Fishery Data Series No. 93-5

Stock Status and Rehabilitation of Chena River Arctic Grayling During 1991 and 1992

by

Robert A. Clark

March 1993

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ABSTRACT

Stock status of Arctic grayling *Thymallus arcticus* in the lower 152 kilometers of the Chena River was described by population abundance, age composition, size composition, recruitment, and survival rate estimates during 1991 and 1992. In July of 1991, estimated abundance of Arctic grayling in the Chena River was 26,756 fish (SE was 3,286 fish) ≥ 150 millimeter fork length. Age 4 Arctic grayling were strongly represented in the Chena River, representing 51.9 percent of fish ≥ 150 millimeter fork length. Stock size Arctic grayling (< 270 millimeter fork length) represented 73.3 percent of fish ≥ 150 millimeter fork length. Annual recruitment between 1990 and 1991 was 2,882 Arctic grayling and annual survival during this period was 74.8 percent.

In July of 1992, estimated abundance of Arctic grayling in the Chena River was 29,349 fish (SE was 2,341 fish) ≥ 150 millimeter fork length. Age 5 Arctic grayling were strongly represented in the Chena River, representing 38.0 percent of fish ≥ 150 millimeter fork length. Stock size Arctic grayling (< 270 millimeter fork length) represented 78.0 percent of fish ≥ 150 millimeter fork length. Annual recruitment between 1991 and 1992 was 5,773 Arctic grayling and annual survival during this period was 78.8 percent. Precision of mark-recapture experiments was improved from prior years by performing single-sample experiments in the entire Lower Chena section (river kilometer 72 to 0). Abundance of Arctic grayling appears to have stabilized, although there was no recreational harvest during the period of stock assessments. Total mortality rate (one minus the survival rate) between 1991 and 1992 could be considered a estimate of natural mortality plus any illegal harvest and incidental hooking mortality.

An egg take was performed during 1992, with approximately 206,000 eggs taken. Of these eggs, approximately 109,500 survived to the 0.5-gram fry stage (38 millimeter fork length). Average fecundity of 49 female Arctic grayling was 3,090 eggs (SD was 1,917 eggs). Approximately 34,000 fry were transferred to a pen rearing facility. A 42 day rearing period resulted in 23,199 2.7-gram fingerlings (65 millimeter fork length) released into the Chena River on 11 September 1992. Persistent cold water temperature delayed maturation of adults during the egg take, possibly causing low egg-to-fry survival. A rearing period of 42 days resulted in less than anticipated growth; earlier maturation of adults in 1993 should result in a longer rearing period for fry. With a longer (60 day) rearing period in 1993, the desired size at release in 1993 should be attained (10 gram or 100 millimeter fork length).

KEY WORDS: Arctic grayling, *Thymallus arcticus*, electrofishing, population abundance, age composition, size composition, Relative Stock Density, recruitment, survival rate, egg take, fecundity, fingerling rearing, Chena River.

INTRODUCTION

Background

The Chena River supports the largest Arctic grayling fishery in North America. For the 13 year period from 1979 to 1991, the Chena River produced an average annual sport harvest of 14,923 Arctic grayling. Average angling effort for all species of fish during this period was in 26,213 angler-days (Table 1). As recently as 1984, annual harvests had exceeded 20,000 fish and 30,000 angler-days of effort (all species), and harvests of Arctic grayling from the Chena River comprised a substantial portion of total Arctic grayling harvests in the Tanana River drainage (Figure 1). However, the status of this fishery has changed since 1984. Recreational harvest of Arctic grayling has declined to historic low levels. Harvest decreased 76% from 1984 to 1985, although angling effort had decreased only 39% (Table 1). Angling effort returned to an average level in 1986, but harvest remained below 10,000 fish. Concomitant with the declining recreational fishery was the decline in Arctic grayling population abundance. Stock assessment projects during 1986 (Clark and Ridder 1987b) and 1987 (Clark and Ridder 1988) documented a decline in population abundance of 49% between these two years. Poor recruitment was the probable cause for a decline in abundance (Holmes 1984, Holmes et al. 1986, Clark 1992a).

During winter of 1986, fishery managers were scheduled to present stock status data (Clark 1986) on the Chena River fishery to the Alaska Board of Fisheries. The Board of Fisheries meeting adjourned before the data could be presented. In spring of 1987, increased concern for the health of the Chena River stock prompted fishery managers to process emergency regulations to reduce harvest. These emergency regulations were:

1) closure of the fishery until the first Saturday in June;

2) a 12 inch (305 mm) minimum total length limit; and,

3) restriction of terminal gear to unbaited artificial lures.

These emergency regulations were made permanent regulations in the summer of 1987. During the winter of 1987, fishery managers presented stock status and regulatory concerns to the Alaska Board of Fisheries (Clark 1987). The emergency regulations imposed in spring of 1987 were adopted and amended. The new permanent regulations were:

1) catch-and-release fishing from 1 April to the first Saturday in June;

2) a 12 inch (305 mm) minimum total length limit from the first Saturday in June until 31 March;

3) restriction of terminal gear to unbaited artificial lures only throughout the Chena River, and bait fishing allowed downstream of the Moose Creek Dam with hooks having a gap larger than 0.75 inch (19 mm);

Table 1. Summary of total angling effort and Arctic grayling harvest on the Chena River, 1977-1991 (taken from Mills (1979-1992).

	Lower Chena River[a]		Upper Chena River[b]		Entire Chena River	
Year	Angler-days	Harvest	Angler-days	Harvest	Angler-days	Harvest
1977[c]	---	---	---	---	30,003	21,723
1978[c]	---	---	---	---	38,341	33,330
1979	9,430	11,290	8,016	11,664	17,446	22,954
1980	13,850	18,520	10,734	16,588	24,584	35,108
1981	11,763	10,814	10,740	13,735	22,503	24,549
1982	18,818	11,117	15,166	12,907	33,984	24,024
1983	17,568	7,894	16,725	10,835	34,293	18,729
1984	20,556	13,850	11,741	12,630	32,297	26,480
1985	11,169	2,923	8,568	3,317	19,737	6,240
1986	18,669	4,167	10,688	3,695	29,357	7,862
1987[d]	12,605	1,230	10,667	1,451	23,272	2,681
1988[d,e]	16,244	2,686	9,677	1,896	25,921	4,582
1989[d,e]	20,317	7,194	10,014	5,441	30,331	12,635
1990[d,e,f]	18,957	3,494	6,949	945	25,906	4,439
1991[d,e,f,g]	12,547	2,997	8,591	722	21,138	3,719
Averages[h]	15,576	7,552	10,637	7,371	26,213	14,923

[a] Lower Chena River is from the mouth upstream to 40 km Chena Hot Springs Road (Mills 1988). In 1991, the Lower Chena River included Badger Slough. Angling effort is for all species of fish.

[b] Upper Chena River is the Chena River and tributaries accessed from the Chena Hot Springs Road beyond 40 km on the road (Mills 1988). Angling effort is for all species of fish.

[c] Angler-days and harvest are computed for the Chena River and Badger Slough.

[d] Special regulations were in effect during 1987 through 1991. These regulations were: catch-and-release fishing from 1 April until the first Saturday in June; a 305 mm (12 inch) minimum length limit; and, a restriction of terminal gear to unbaited artificial lures.

[e] In addition to the special regulations, a catch-and-release area was created on the Upper Chena River (river km 140.8 to 123.2).

[f] The daily bag and possession limits were reduced from five fish to two fish in 1990.

[g] During 1991, the Chena River and its tributaries were closed to possession of Arctic grayling from 1 July through 31 December.

[h] Averages are for 1979 through 1991 only.

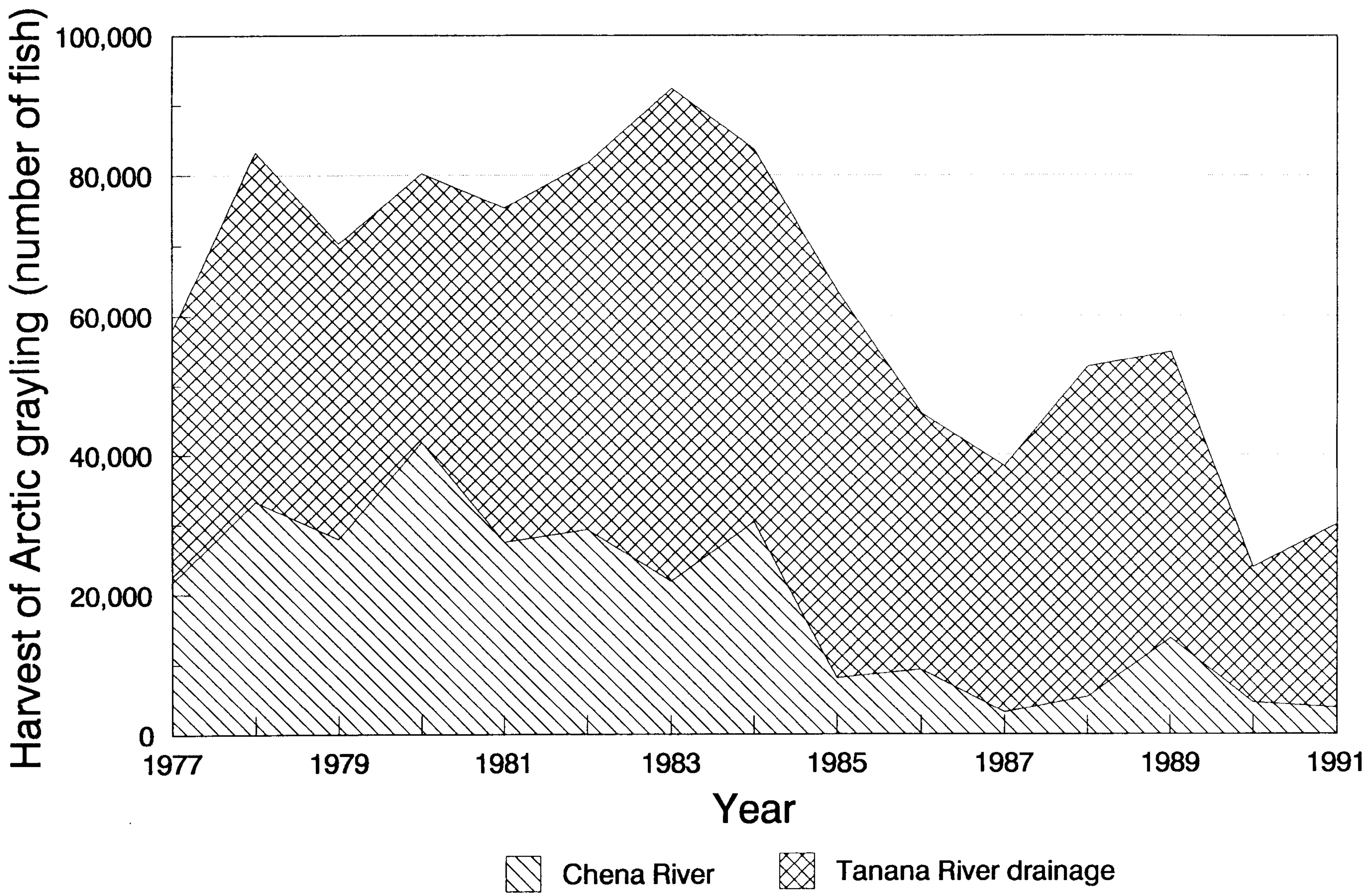

Figure 1. Annual harvests of Arctic grayling in the Chena River and in the entire Tanana River drainage excluding the Chena River, 1977-1991 (taken from Mills 1979-1992).

4) catch-and-release fishing year around from river kilometer 140.8 downstream to river kilometer 123.2; and,

5) reduce the possession limit from 10 to 5 fish (Tanana River drainage regulation).

The regulations adopted by the Board of Fisheries in winter of 1987 were the first changes in Arctic grayling management since 1975, when the daily bag limit was decreased from 10 to 5 fish. Evaluation of the effects of new regulations on the Arctic grayling stock and recreational anglers was begun in 1987.

In 1990, continued concern for the Arctic grayling stock in the Chena River prompted the Board of Fisheries to implement a daily bag limit of two fish, riverwide, and single hook regulations upstream of the Moose Creek Dam. On 1 July 1991, fishery managers invoked Emergency Order authority to reduce the daily bag limit to 0 fish in the entire Chena River drainage. This Emergency Order remained in effect through 1992.

Concomitant with a daily bag limit of 0 fish, fishery managers began a rehabilitation program for Arctic grayling in the Chena River. The rehabilitation program has two main parts: regulation changes to ensure adequate protection of the stock, and a program of supplementation of natural production with releases of hatchery and pond raised Arctic grayling. The proposed rehabilitation effort will last three years, after which, fishery managers will enact fishery regulations to ensure sustained harvests of Arctic grayling. Beginning in spring of 1992, the first lot of fertilized eggs were taken from the Chena River stock for use in supplementing natural production.

Objectives for Stock Assessment

In order to accurately and precisely describe the stock status of Arctic grayling in the Chena River, the following objectives were addressed in 1991 and 1992 and these pertain to Federal Aid contracts F-10-7, F-10-8, Job No. R-3-2a:

1) to estimate the abundance of Arctic grayling ≥ 150 mm fork length (FL) in the lower 152 km of the Chena River;

2) to estimate the age composition of Arctic grayling in the lower 152 km of the Chena River; and,

3) to estimate the size composition of Arctic grayling in the lower 152 km of the Chena River.

In addition to these primary objectives, recruitment of new fish to the stock and the annual survival rate of the stock were estimated.

As part of the Chena River Restoration Plan for Arctic grayling, an egg take was performed at the Chena River during May and June of 1992. Objectives of the egg take (under Federal Aid contract F-32-1) were to:

1. collect approximately 200,000 fertilized eggs from wild Arctic grayling in the Chena River; and,

2. sample 60 female Arctic grayling for ovarian fluid.

In addition, data concerning age and size at maturity, and fecundity at age and size were collected during the egg take.

METHODS

Sampling Gear and Techniques

During 1991 and 1992, all sampling was performed with pulsed-DC (direct current) electrofishing systems mounted on 6.1 m long river boats as previously described by Lorenz (1984). Input voltage (240 VAC) was provided by a 3,500 or 4,000 W single-phase gas powered generator. A variable voltage pulsator (Coffelt Manufacturing Model VVP-15) was used to generate output current. Anodes were constructed of 16.0 mm diameter and 1.5 m long twisted steel cable. Four anodes were attached to the front of a 3 m long "T-boom" attached to a platform at the bow of the river boat. The aluminum hull of the river boat was used as the cathode. Output voltages during sampling varied from 200 to 300 VDC. Amperage varied from 2.5 to 4.0 A. Duty cycle and pulse rate were held constant at 50% and 60 Hz, respectively. These operating characteristics were presumed to minimally affect Arctic grayling survival during mark-recapture experiments. Water conductivity ranged from 125 μS to 170 μS (at 25°C) during electrofishing.

Sampling was conducted along the banks of the Chena River. Two electrofishing boats were each directed downstream along one bank, capturing all Arctic grayling seen, when possible. Captured Arctic grayling were held in an aerated holding tub to reduce capture related stress. The two river sections were sampled no more than once per day to prevent changes in capture probabilities of marked fish (Cross and Stott 1975). Each Arctic grayling was measured to the nearest 1 mm FL. A sample of scales was taken from an area approximately six scale rows above the lateral line just posterior to the insertion of the dorsal fin of each newly captured Arctic grayling. Arctic grayling $\geq$ 150 mm FL were marked with individually numbered Floy FD-68 internal anchor tags inserted at the base of the dorsal fin. The tip of the left pectoral fin was removed in 1991 and the tip of the right pectoral fin was removed in 1992 to identify marked fish in case the numbered tag was shed. If any captured Arctic grayling exhibited signs of injury or imminent mortality, they were immediately sacrificed.

Estimation of Abundance

The abundance of Arctic grayling $\geq$ 150 mm FL was estimated by mark-recapture techniques in the lower 152 km of the mainstem Chena River (Figure 2). Two sections of the Chena River were delineated for separate estimation experiments. Delineation of the Chena River was necessary because of differences in capture probability of Arctic grayling in different sections of

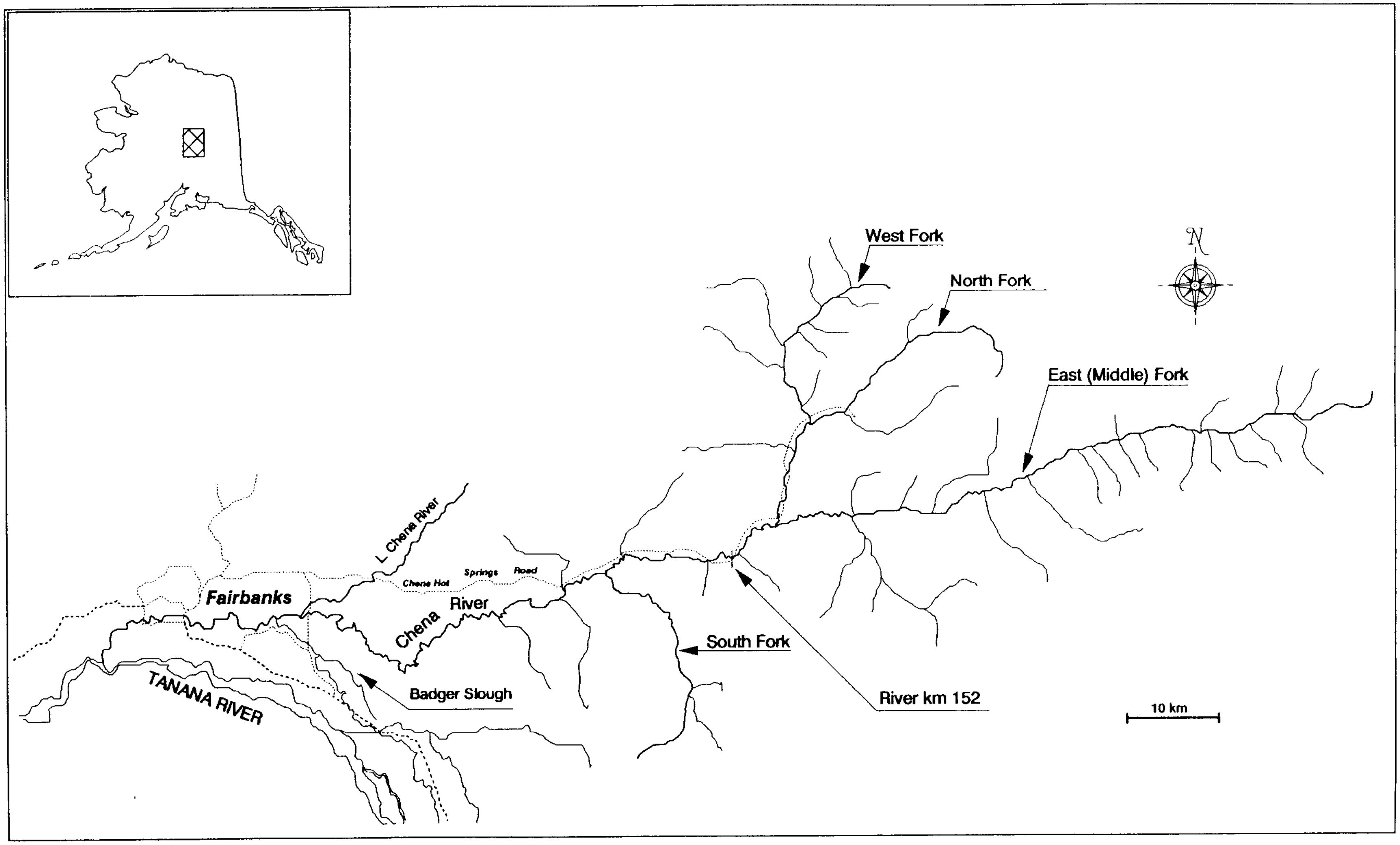

Figure 2. The Chena River drainage.

river (Figure 3). Based on differences in capture probability from downstream to upstream areas of the Chena River, the lower 152 km of the Chena River is divided into Lower and Upper sections for estimating abundance and age composition. Downstream from the Moose Creek Dam complex to the mouth of the Chena River was designated the Lower Chena section (72 km long; Figure 4). Upstream from the dam to the first bridge on the Chena Hot Springs Road (kilometer 62.4) was designated the Upper Chena section (80 km long; Figure 4). Population abundance estimates pertain only to these two sections of the Chena River, excluding Badger Slough, the Little Chena River, and the South Fork of the Chena River.

Clark (1991) found that precision of abundance estimates in the Lower Chena section was much less than for abundance estimates in the Upper Chena section. The disparity in precision could be accounted for by differences in sampling design and sampling effort. In 1990, sampling design for the Lower Chena consisted of two sets of abundance estimates performed in 3.2 km sample areas, averaged in each of two subsections, and then expanded by the total number of river kilometers represented in each subsection. Sampling effort in the Lower Chena was 24 crew-days. Conversely, abundance of Arctic grayling in the Upper Chena was estimated during 1990 with a mark-recapture experiment encompassing the entire section of river. Sampling effort in the Upper Chena was 48 crew-days. During 1991 and 1992, 48 crew-days of sampling effort and a sample design encompassing the entire Lower Chena section were used to improve CV of abundance estimates in the Lower Chena. Abundance estimates in each section of the Chena River were calculated in an identical manner.

Abundance of Arctic grayling $\geq$ 150 mm FL was estimated with the modified Petersen estimator of Bailey (1951, 1952). Two electrofishing boats were used to mark Arctic grayling along both banks of the Lower (72 km long) and Upper Chena (80 km long) sections. Marking of fish in each section required four days. After a hiatus of seven days the two electrofishing boats were used in the same way to capture marked and unmarked Arctic grayling. The Lower Chena experiment was conducted during the first two weeks of July and the Upper Chena experiment was conducted during the last two weeks of July 1991 and 1992.

The assumptions necessary for accurate estimation of abundance in a closed population are (from Seber 1982):

1) the population is closed (no change in the number of Arctic grayling in the population during the estimation experiment);

2) all Arctic grayling have the same probability of capture in the first sample <u>or</u> in the second sample, <u>or</u> marked and unmarked Arctic grayling mix randomly between the first and second samples;

3) marking of Arctic grayling does not affect their probability of capture in the second sample;

4) Arctic grayling do not lose their mark between sampling events; and,

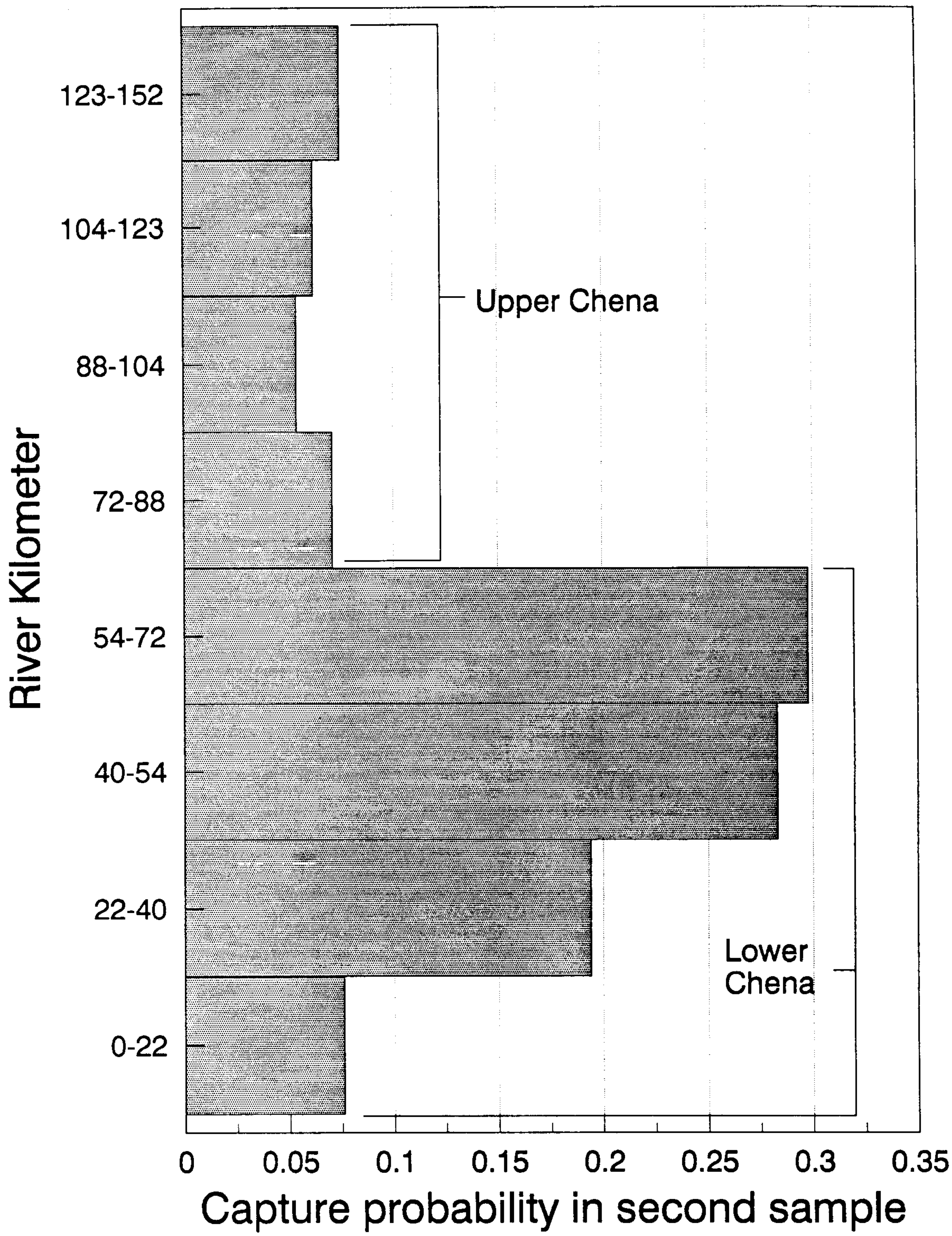

Figure 3. Recapture-to-catch ratios of Arctic grayling (≥ 150 mm FL) in eight reaches of the Chena River in 1991.

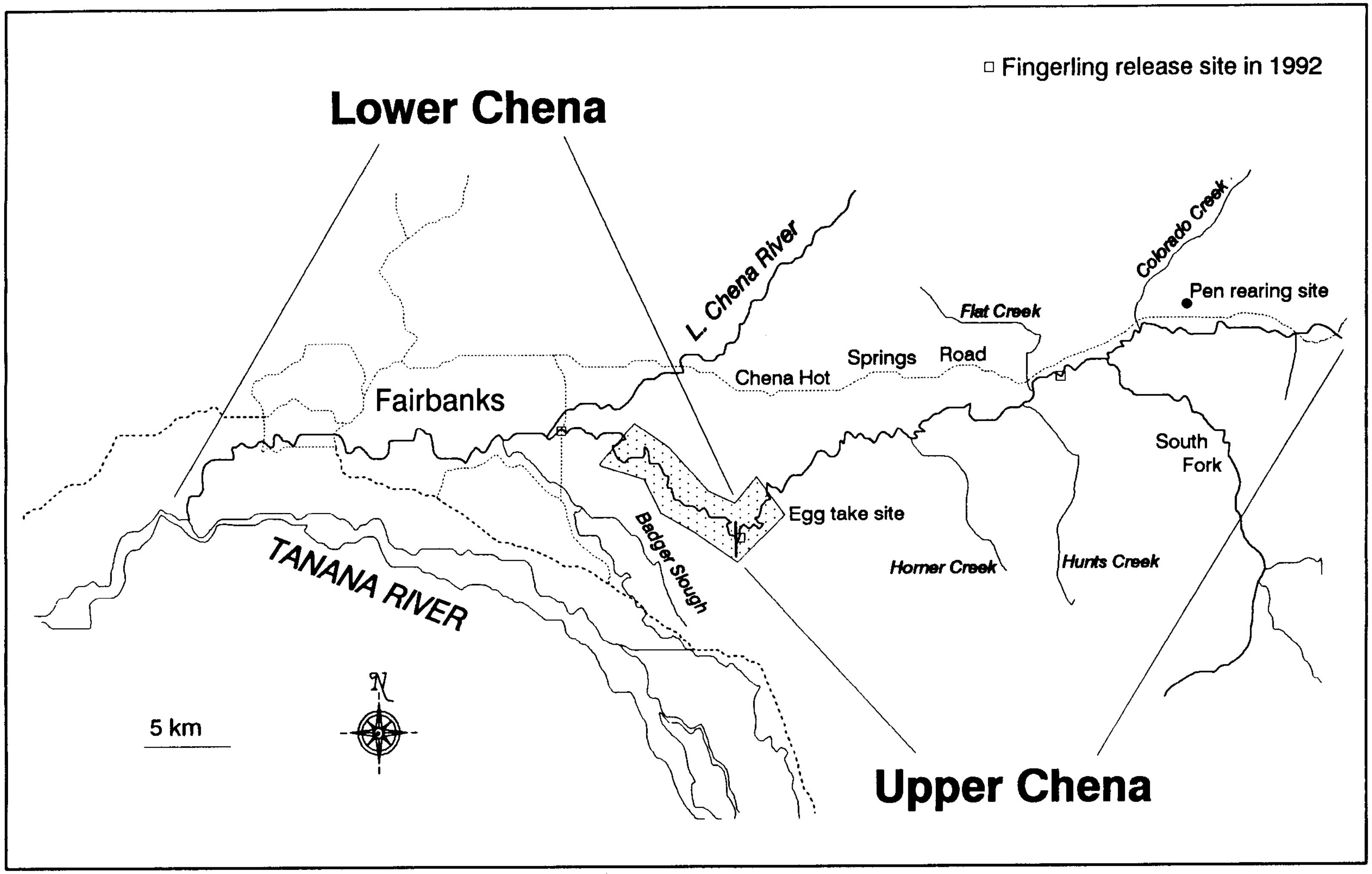

Figure 4. Stock assessment sections in 1991 and 1992, egg take site in 1992, and fingerling release sites in 1992 along the lower 152 km of the Chena River drainage.

5) all marked Arctic grayling are reported when recovered in the second sample.

Assumption 1 was assumed because of the large size of the sections (72 and 80 km) and short duration of the experiments (two weeks). Assumptions 2 and 3 that relate to changes in capture probability by size of fish were tested with two Kolmogorov-Smirnov (K-S) statistical tests. The first test compared the length frequency distributions of recaptured Arctic grayling with those captured during the marking runs. The second test compared the length frequency distributions of Arctic grayling captured during the marking runs with those captured in the recapture runs (see Bernard and Hansen 1992 for a description of tests). In addition, sampling was conducted with equal effort along each section of river, so it was assumed that all Arctic grayling had equal probability of capture throughout each section. The assumption of equal probability of capture along entire river sections was tested with a chi-square contingency table. The recapture to catch ratios were compared for the four areas within each river section. Assumptions 4 and 5 were assumed to be valid because of double marking of tagged Arctic grayling and rigorous examination of all captured Arctic grayling.

Estimated abundance was calculated from numbers of Arctic grayling marked, examined for marks, and recaptured (Bailey 1951; Seber 1982):

$$\hat{N}_i = \frac{n_1 (n_2 + 1)}{(m_2 + 1)} \qquad (1)$$

where:
- n_1 = the number of Arctic grayling marked and released alive during the first sample in river section i;
- n_2 = the number of Arctic grayling examined for marks during the second sample in river section i;
- m_2 = the number of Arctic grayling recaptured during the second sample in river section i; and,
- $\hat{N}_i$ = estimated abundance of Arctic grayling during the first sample in river section i.

Variance was estimated by (Seber 1982):

$$\hat{V}[\hat{N}_i] = \frac{n_1^2 (n_2 + 1)(n_2 - m_2)}{(m_2 + 1)^2 (m_2 + 2)} \qquad (2)$$

Bailey's (1951, 1952) modification was used instead of the more familiar modification by Chapman (1951) because of the sampling design used on each river section. Seber (1982) found that if the assumption of a random sample for the second sample was false and a systematic sample was taken (for example, a systematic sample of both banks of the Chena River), then the binomial model of Bailey (1951, 1952) is most appropriate. The binomial model will hold in this situation when:

1) there is uniform mixing of marked and unmarked fish; and,

2) all fish, whether marked or unmarked, have the same probability of capture.

The sample design used in each river section does not allow for thorough mixing of fish marked at the uppermost reaches with those marked in the downstream reaches, although local mixing of marked and unmarked fish probably occurs.

Additionally, statistical bias of each abundance estimate was investigated by bootstrapping the estimation experiments (Efron 1982). First, capture history of each fish was recorded. Two columns of data were constructed; the first column represented the first, or marking event, and the second column represented the second, or recapture event. A capture in a particular event was denoted with a 1; if the fish was not seen during the event, this was denoted by a zero. The total number of capture histories was the sum of fish marked in the fish event plus fish examined in the second event minus the number of fish seen in both events (recaptures). These capture histories were then resampled, at random, with replacement 1,000 times by computer. Each replication of the estimation experiment involved sampling of "the total number of capture histories" and then calculating an abundance estimate. After 1,000 replications the mean and sample variance (Snedecor and Cochran 1980) were calculated for all replicates:

$$\hat{N}_B = \frac{\sum_{j=1}^{1,000} \hat{N}_j}{1,000} \tag{3}$$

where:

$\hat{N}_B$ = the bootstrap mean of 1,000 replicates of the mark-recapture experiment;

$\hat{N}_j$ = the jth bootstrap replicate of the mark-recapture experiment; and,

$$\hat{V}[\hat{N}_B] = \frac{\sum_{j=1}^{1,000} (\hat{N}_j - \hat{N}_B)^2}{1,000 - 1} \tag{4}$$

where:

$\hat{V}[\hat{N}_B]$ = the bootstrap variance of N_B.

Bias was calculated as the absolute difference between abundance estimates from equations 1 and 3 expressed as a percentage of the bootstrap estimate in equation 3 (ignoring hat symbols):

$$\text{Bias}(\%) = \frac{|N_i - N_B|}{N_B} \times 100\% \tag{5}$$

Estimated abundance and variance in the lower 152 km of the Chena River was calculated as the sum of Lower Chena section and Upper Chena section estimates:

$$\hat{N} = \sum_{i=1}^{2} \hat{N}i; \quad \text{and,} \tag{6}$$

$$\hat{V}[\hat{N}] = \sum_{i=1}^{2} \hat{V}[\hat{N}_i]. \tag{7}$$

Estimation of Age and Size Composition

Collections of Arctic grayling for age-length samples were conducted in conjunction with abundance estimation experiments. The Lower Chena section age-length samples were analyzed independently of the Upper Chena section age-length samples.

Age composition of Arctic grayling in each of the river sections could have been calculated directly from age-length samples taken during the first sample of the mark-recapture estimate. However, a statistical difference in the capture probabilities by lengths of fish was detected in each section (from tests of assumptions 2 and 3). Using the estimates of capture probability by size class, adjustment factors were estimated and used to correct for the bias. First, the capture probabilities were estimated from the recapture to mark ratios in each of two size classes:

$$\hat{\rho}_l = \frac{RECAP_l}{MARK_l} \tag{8}$$

where: $\hat{\rho}_l$ = the capture probability of Arctic grayling in size class l, regardless of age k;
$RECAP_l$ = the number of recaptures of Arctic grayling in size class l; and,
$MARK_l$ = the number of marked Arctic grayling in size class l.

Size classes were chosen by performing a series of chi-square contingency table tests to determine the largest possible significant chi-square test statistic among all possible sets of stratification. These tests were restricted to the case of only two size classes, because further stratification could potentially reduce precision with no appreciable increase in accuracy.

From the ratio of the largest capture probability to the capture probability in size class l, an adjustment to the number sampled at age k that are also of size class l was estimated (ignoring the hat symbols of ρ):

$$\hat{A}_l = \frac{\rho_L}{\rho_l} \tag{9}$$

where: $\hat{A}_l$ = the adjustment factor for all Arctic grayling of size class l, regardless of age class k; and,

$\rho_L = \max(\rho_l)$, $l = 1, 2$ size classes (represented by m).

The adjustment factor was multiplied by the number of Arctic grayling sampled at age k that were also in size class l:

$$\hat{x}_{kl} = \hat{A}_l \, n_{kl} \tag{10}$$

where: $\hat{x}_{kl}$ = the adjusted number of Arctic grayling of age k that were also in size class l; and,

n_{kl} = the actual number of Arctic grayling sampled that were age k and also in size class l.

The proportion of Arctic grayling that were age k then reevaluates to:

$$\hat{p}_k = \frac{\sum_{l=1}^{m} \hat{x}_{kl}}{\sum_{k=1}^{o} \sum_{l=1}^{m} \hat{x}_{kl}} = \frac{\hat{x}_{k.}}{\hat{x}_{..}} \tag{11}$$

where: $k = 1, 2, \ldots, o$ age classes; and,

$l = 1, 2$ size classes (represented by m).

The variances of these adjusted proportions were estimated by bootstrap techniques (Efron 1982). The adjustment factors (recapture to mark ratios) from bootstrapping of capture histories were used to estimate variance of the proportions.

Abundance at age in each river section was estimated by multiplying the proportion at age by the abundance estimate for each river section. Variance of abundance at age was calculated with the formula of Goodman (1960) for the product of two independent variables. Abundance at age in the entire Chena River was estimated by adding estimates for each age class from each river section. Variance of abundance at age was calculated in the same way.

Size composition of Arctic grayling in each of the river sections was described with the incremental Relative Stock Density (RSD) indices of Gabelhouse (1984). The RSD categories are: "stock" (150 to 269 mm FL); "quality" (270 to 339 mm FL); "preferred" (340 to 449 mm FL); "memorable" (450 to 559 mm FL); and, "trophy" (greater than 559 mm FL). The same adjustment factors (equation 9) used to compensate for bias in age composition were used to adjust biased RSD estimates. The number sampled at age k that were also in size class l (n_{kl}) in equation 10 was replaced with the number sampled in RSD category k (k = 1, 2, 3, 4, and 5 RSD categories) that were also in size class l.

Adjusted proportions at age and size from the Lower and Upper Chena sections were then combined to estimate proportions at age and size for the lower 152 km of the Chena River. First, the adjusted proportions for each river section were averaged by weighting with the section abundance estimates and the estimate of abundance for the lower 152 km of the Chena River:

$$\hat{\bar{p}}_k = \sum_{i=1}^{2} \frac{\hat{N}_i}{\hat{N}} \hat{p}_{ik} \tag{12}$$

where: $\hat{\bar{p}}_k$ = the average weighted proportion of Arctic grayling in the lower 152 km of the Chena River that were age or size k;
$\hat{N}_i$ = the abundance of Arctic grayling in section i (N_L and N_U);
$\hat{N}$ = $\hat{N}_L + \hat{N}_U$ (total abundance); and,
$\hat{p}_{ik}$ = the proportion of Arctic grayling in section i that were age or size k.

Variance of the proportions were approximated with the delta method (see Seber 1982):

$$\hat{V}[\hat{\bar{p}}_k] \approx \sum_{i=1}^{2} (\hat{p}_{ik} - \hat{\bar{p}}_k)^2 \frac{\hat{V}[\hat{N}_i]}{\hat{N}^2} + \sum_{i=1}^{2} (\hat{N}_i/\hat{N})^2 \hat{V}[\hat{p}_{ik}] \tag{13}$$

These average weighted proportions and variances by age were used as estimates of age composition in the lower 152 km of the Chena River.

<u>Estimation of Survival and Recruitment</u>

As of 1992, seven years of population abundance and age composition estimates had been completed for the lower 152 km of the Chena River. Using data from 1986 through 1990, Clark (1991) reported on survival rates and recruitment for 1986 through 1989. Survival rate and recruitment for 1990 and 1991 were calculated in the same manner.

Annual recruitment was defined as the number of age 3 Arctic grayling added to the population between year t and year $t+1$, and alive in year $t+1$. Estimates of recruitment were simply the estimates of abundance of age 3 Arctic grayling in 1990 through 1992. Variance of the recruitment estimates were the variance of abundance at age 3 for these same years

With recruitment and abundance at age estimates in years t and $t+1$, the estimate of survival rate between year t and year $t+1$ was:

$$S_{t,t+1} = \frac{\hat{N}'_{t+1}}{\hat{N}_t} \tag{14}$$

where: $\hat{N}'_{t+1} = \sum_{k=4}^{12} \hat{N}_{t+1,k}$

= the abundance of age k and older Arctic grayling in year t+1; and,

$\hat{N}_t = \sum_{k=3}^{12} \hat{N}_{t,k}$

= the abundance of age k and older Arctic grayling in year t.

The variance of annual survival was approximated as the variance of a quotient of two independent variables with the delta method (Seber 1982; ignoring hat symbols):

$$V[S] \approx \left[\frac{N'_{t+1}}{N_t} \right]^2 \left[\frac{V[N'_{t+1}]}{N'^{2}_{t+1}} + \frac{V[N_t]}{N_t^2} \right] \tag{15}$$

where: $V[N'_{t+1}] = \sum_{k=4}^{12} V[N_{t+1,k}]$; and,

$V[N_t] = \sum_{k=3}^{12} V[N_{t,k}]$.

Egg Take and Fingerling Rearing

Collection of mature fish was performed during 14 through 20 May 1992. A single electrofishing boat, as described above, was used to sample both banks of the Chena River from river kilometer 48 to river kilometer 80 (Figure 4). Maturity of fish was determined with methods described in Clark (1992b). Fish were separated by sex and held in two 1.2 m square wooden pens with 19 mm plastic mesh. Pens were located in a slough of the Chena River near the Moose Creek Dam complex (river kilometer 72). Maturation of fish was checked every third day after capture and ripe fish were transferred to two similar pens.

Fish were artificially spawned on 27 May, 1, 6, and 10 June. During spawning, each fish was sexed, measured for length, tagged with an individually number Floy anchor tag, and released. Female fish were spawned individually into a 0.1 L paper cup and the sperm from two males added immediately. A small amount of water was added to activate the sperm. After at least 1 min the fertilized eggs were washed to remove excess sperm and other debris, and then placed in separate 0.5 L plastic containers filled with water. To identify each container of fertilized eggs, each container was marked with a unique number to identify the female fish from which the eggs were taken. Egg containers were placed in an ice cooler and lightly iced to maintain a temperature of 3.5°C. Fertilized eggs were then transported to Clear Hatchery. At the hatchery, the water was poured from the egg containers and Betadine (1:100 solution) added to the container to disinfect the fertilized eggs. After 10 min in the disinfectant, the fertilized eggs were drained and enumerated using the volumetric method. Total changes in volume were recorded for each container of fertilized eggs. To estimate an expansion for change in volume to estimated number of eggs per female, a subsample of eggs from every fifth container were measured volumetrically and the sample of eggs counted. It was assumed that egg size and volume per egg did not vary considerably from fish to fish. The fertilized eggs from 10 females were placed in a single Heath incubator tray and incubated at 10°C. To prevent fungal infection, fertilized eggs were treated with formalin (1:600 solution) for every other day until hatching

After hatching, Arctic grayling fry were reared at Clear Hatchery until reaching an average weight of 0.5 g per fish. Approximately 70,000 fry were to be transported from the hatchery to a pen rearing facility located at an abandoned borrow pond at kilometer 52.6 (mile 32.9) of the Chena Hot Springs Road (Figure 4). Due to low survival rate from egg to fry at the hatchery, an estimated 33,868 fry (based on weight) were delivered to the facility on 30 July. Fry were reared for 42 days in a floating net pen (3.6 m square and 3.6 m deep with 3 mm meshes). Fry were fed a commercial fish feed during the rearing period. Fork length and weight were measured from a sample of 200 fry every two weeks during the rearing period. Water temperature was monitored continuously at depths of 0.1, 1.8, and 3.6 m.

On 11 September the fingerlings were transported to three release sites on the Chena River (Figure 4). Approximately equal lots of fish were released at each site. Fork length and weight were measured from a sample of 150 fingerlings prior to release. A sample of scales was taken from 50 fingerlings. In order to detect these fish during stock assessment in future years, all fingerlings were given an adipose fin clip.

Historic Data Summary

Data collected from the Chena River (1955 to 1992) were summarized in Appendix A. Creel survey estimates, population abundance estimates, length at age estimates, age composition estimates, size composition estimates, and a model of Arctic grayling growth were summarized from Federal Aid in Sport Fish Restoration reports and State of Alaska Fishery Data Series reports written from 1959 to the present (Appendix A). When possible, estimates of precision were reported with point estimates. Precision was reported as either standard error or 95% confidence interval. Sample sizes were reported if neither of these estimates of precision were available. Length frequency was generally reported in the literature as numbers sampled per 10 mm length increment. The length frequency distributions were converted into the RSD categories of Gabelhouse (1984) for comparison with data collected from 1986 to 1992. In addition to the aforementioned reports in Appendix A, Arctic grayling migration studies were summarized in a report by Tack (1980). Reports concerning Arctic grayling research from 1952-1980 were compiled by Armstrong (1982). Armstrong et al. (1986) have compiled a bibliography for the genus *Thymallus* to 1985.

RESULTS

Stock Assessment in 1991

The Lower Chena experiment was performed during 8 through 18 July 1991. A total of 1,156 fish were marked, 848 fish were examined for marks, and 180 fish were recaptured during mark-recapture sampling. Eleven immediate mortalities or serious injuries were recorded for an overall injury rate of 0.6%. Recapture-to-catch ratios varied significantly among four areas of the Lower Chena ($\chi^2 = 29.38$, df = 3, $P = 2.00 \times 10^{-6}$; Figure 3). However, two of these four areas had similar recapture-to-catch ratios and were combined. There was no movement of marked fish between the four areas. Abundance, and age and size compositions were estimated separately in each of the resultant three areas. The three areas were: river kilometer 0 to 24; river kilometer 24 to 40; and, river kilometer 40 to 72 (see Table 2). No significant change in capture probability by size of fish occurred in river kilometer 40 to 72 ($D = 0.12$, $P = 0.21$). Size selective sampling appeared to have occurred in river kilometer 0 to 24 ($D = 0.30$, $P = 0.55$), but there were too few recaptures to stratify the experiment by size. Additionally, the smallest recapture in river kilometer 0 to 24 was 190 mm FL (Figure 5). Based on recaptures as small as 165 mm FL observed in other areas of the Lower Chena and the need to estimate abundance of fish ≥ 150 mm FL in all areas of the Lower Chena, the data were not truncated to 190 mm FL. There was a marginally significant change in capture probability by size in river kilometer 24 to 40 ($D = 0.16$, $P = 0.08$; Figure 5). The experiment in river kilometer 24 to 40 was stratified into small (150 to 205 mm FL) and large (greater than 205 mm FL) size classes (Table 2). The summed estimate of abundance in the Lower Chena section was 6,526 fish (SE = 701 fish).

There were no functional difference in the frequency distributions of fish marked versus those examined for marks in any of the three areas used for abundance estimation (Figure 5). Results of K-S tests were: D = 0.09, P = 0.49 for river kilometer 0 to 24; D = 0.05, P = 0.56 for river kilometer 24 to 40; and, D = 0.12, P = 0.01 for river kilometer 40 to 72. After combining estimates of age composition from each of the three areas in the Lower Chena section (equations 12 and 13), age 4 fish were most abundant in this section of river (Table 3). Ages 2 through 4 comprised 72% of abundance, with very few fish older than age 8 in the Lower Chena. Similarly, stock size fish comprised 78% of abundance in the Lower Chena while only 1% of fish in the Lower Chena were of preferred size (Table 4).

Table 2. Capture probabilities and estimated abundance in three areas used for population estimation of Arctic grayling (≥ 150 mm FL) in the Lower Chena section of the Chena River, 8 through 18 July 1991.

River km	Mark n_1	Catch n_2	Recap m	ρ[a]	SE[ρ][b]	N[c]	SE[N][d]
0 to 24	162	145	11	0.07	0.02	1,971	524
24 to 40[e]							
150-205 mm FL	93	90	6	0.06	0.03	1,209	411
≥ 206 mm FL	358	282	68	0.19	0.02	1,468	153
40 to 72	543	331	95	0.17	0.01	1,878	161
Total	1,156	848	180	---	---	6,526	701

[a] ρ is the probability of capture determined from bootstrap methods.
[b] SE[ρ] is the standard error of ρ determined from bootstrap methods.
[c] N is the estimated abundance in an area and/or length category.
[d] SE[N] is the standard error of N.
[e] Abundance in river kilometer 24 to 40 was stratified by size to adjust for gear selectivity.

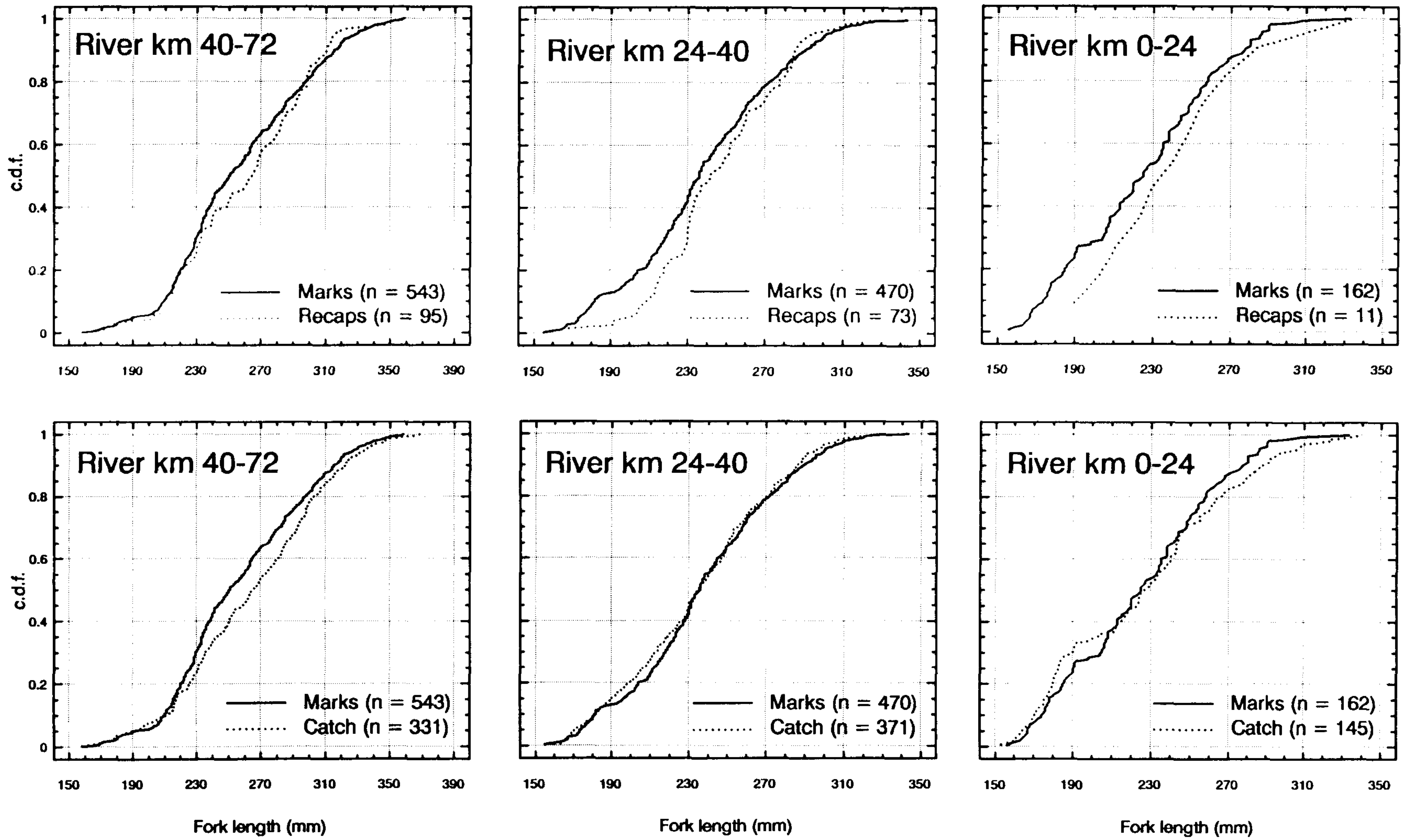

Figure 5. Cumulative density functions (c.d.f.) of fork length of Arctic grayling marked, captured, and recaptured in three areas of the Lower Chena section of the Chena River, 8 through 18 July 1991.

Table 3. Estimates of adjusted age composition and abundance by age class with standard errors for Arctic grayling (≥ 150 mm FL) captured by pulsed-DC electrofishing from the Lower Chena section of the Chena River, 8 through 11 July 1991.

	Age Composition				Abundance		
Age	n[a]	p[b]	SE[c]	CV[d]	N[e]	SE[f]	CV[g]
2	115	0.22	0.04	17.4	1,455	297	20.4
3	147	0.20	0.02	8.6	1,290	177	13.7
4	376	0.30	0.02	7.1	1,958	252	12.8
5	118	0.10	0.01	13.5	647	111	17.2
6	79	0.06	0.01	15.0	391	72	18.4
7	98	0.07	0.01	12.8	456	76	16.7
8	66	0.04	0.01	16.0	261	50	19.2
9	12	0.01	<0.01	27.1	46	13	28.3
10	6	<0.01	<0.01	40.0	23	9	39.1
11	0	0	0	---	0	0	---
Total	1,017	1.000	---	---	6,526	701	10.7

[a] n = number of Arctic grayling sampled at age.
[b] p = estimated adjusted proportion of Arctic grayling at age in the population. Calculated with bootstrap methods (Efron 1982).
[c] SE = estimated standard error of p. Calculated with bootstrap methods (Efron 1982).
[d] CV = coefficient of variation of p, expressed as a percentage of p.
[e] N = estimated population abundance of Arctic grayling at age.
[f] SE = estimated standard error of N (Seber 1982).
[g] CV = coefficient of variation of N, expressed as a percentage of N.

Table 4. Summary of Relative Stock Density (RSD) indices of Arctic grayling (≥ 150 mm FL) captured in the Lower and Upper Chena sections, and the Chena River, 1991.

	RSD Category[a]				
	Stock	Quality	Preferred	Memorable	Trophy
Lower Chena					
Number sampled	1,432	553	26	0	0
RSD	0.71	0.28	0.01	0.00	0.00
Adjusted RSD[b]	0.78	0.21	0.01	0.00	0.00
Standard Error	0.02	0.02	<0.01	0.00	0.00
Abundance	5,100	1,366	60	0	0
Standard Error	561	187	16	0	0
Upper Chena					
Number sampled	1,155	632	152	0	0
RSD	0.59	0.33	0.08	0.00	0.00
Adjusted RSD[b]	0.72	0.25	0.03	0.00	0.00
Standard Error	0.02	0.01	0.01	0.00	0.00
Abundance	14,513	5,033	684	0	0
Standard Error	2,328	829	169	0	0
Chena River					
Number sampled	2,587	1,185	178	0	0
RSD	0.65	0.30	0.05	0.00	0.00
Adjusted RSD[b]	0.73	0.24	0.03	0.00	0.00
Standard Error	0.01	0.01	<0.01	0.00	0.00
Abundance	19,613	6,399	744	0	0
Standard Error	2,395	850	170	0	0

[a] Minimum lengths for RSD categories are (Gabelhouse 1984):
stock - 150 mm FL; quality - 270 mm FL; preferred - 340 mm FL; memorable - 450 mm FL; and, trophy - 560 mm FL.

[b] Adjusted RSD is the RSD corrected for differential vulnerability by length from electrofishing. The adjustment is made with bootstrapping methods (Efron 1982). Standard error of RSD is for the adjusted estimate.

The Upper Chena experiment was performed during 22 July through 1 August 1991. A total of 1,097 fish was marked, 901 fish was examined for marks, and 59 fish was recaptured during mark-recapture sampling. Thirteen immediate mortalities or serious injuries were recorded for an overall injury rate of 0.7%. Recapture-to-catch ratios did not vary significantly among four areas of the Upper Chena ($\chi^2 = 0.91$, df = 3, $P = 0.82$; Figure 3). There was a significant change in capture probability by size in Upper Chena section ($D = 0.27$, $P \approx 4.75 \times 10^{-4}$; Figure 6). However, there was no significant difference in the length frequency of fish marked versus fish examined for marks ($D = 0.04$, $P \approx 0.26$; Figure 6). The experiment was stratified into small (150 to 297 mm FL) and large (greater than 297 mm FL) size classes (Table 5). The summed estimate of abundance in the Upper Chena section was 20,230 fish (SE = 3,210 fish). If mark-recapture were not stratified by size, the resulting estimate of abundance would have been 16,491 fish with a bias of 18.5% (see also Appendix B1).

Age 4 fish were also most abundant in the Upper Chena section, accounting for 59% of abundance (Table 6). Ages 3 through 5 comprised 78% of abundance, with very few fish older than age 8 in the Upper Chena. Stock size fish comprised 72% of abundance, while only 3% of fish in the Upper Chena were of preferred size (Table 4).

Estimated abundance of Arctic grayling ($\geq$ 150 mm FL) in the lower 152 km of the Chena River in 1991 was 26,756 fish (SE = 3,286 fish). Age 4 fish represented 52% of the Arctic grayling population (Table 7). Stock size fish accounted for 73% of the population (Table 4). Abundance of age 3 and older Arctic grayling was 24,657 fish (SE = 2,082 fish). Survival rate of age 3 and older fish from 1990 to 1991 was 0.75 (SE = 0.13). Recruitment from 1990 to 1991 (age 3 fish) was 2,882 fish (SE = 368 fish). Data files used to estimate abundance, and age and size composition are listed in Appendix C1.

<u>Stock Assessment in 1992</u>

The Lower Chena experiment was performed during 6 through 16 July 1992. A total of 1,756 fish were marked, 1,371 fish were examined for marks, and 287 fish were recaptured during mark-recapture sampling. Forty-two immediate mortalities or serious injuries were recorded for an overall injury rate of 1.5%. Recapture-to-catch ratios did not vary significantly among four areas of the Lower Chena ($\chi^2 = 3.00$, df = 3, $P \approx 0.39$; Figure 7). There was no movement of marked fish between the four areas. A single estimate of abundance was calculated for the Lower Chena section. There was significant size selective sampling in the Lower Chena ($D = 0.15$, $P \approx 2.02 \times 10^{-5}$; Figure 8). The experiment was therefore stratified into small (150 to 208 mm FL) and large (greater than 208 mm FL) size classes (Table 8). The summed estimate of abundance in the Lower Chena section was 11,316 fish (SE = 1,294 fish).

The frequency distributions of fish marked versus those examined for marks in the Lower Chena did not differ ($D = 0.04$, $P \approx 0.09$; Figure 8). After adjustment for size selective sampling, age 3 fish were most abundant in this section of river (Table 9). Ages 2 through 5 comprised 84% of abundance, with

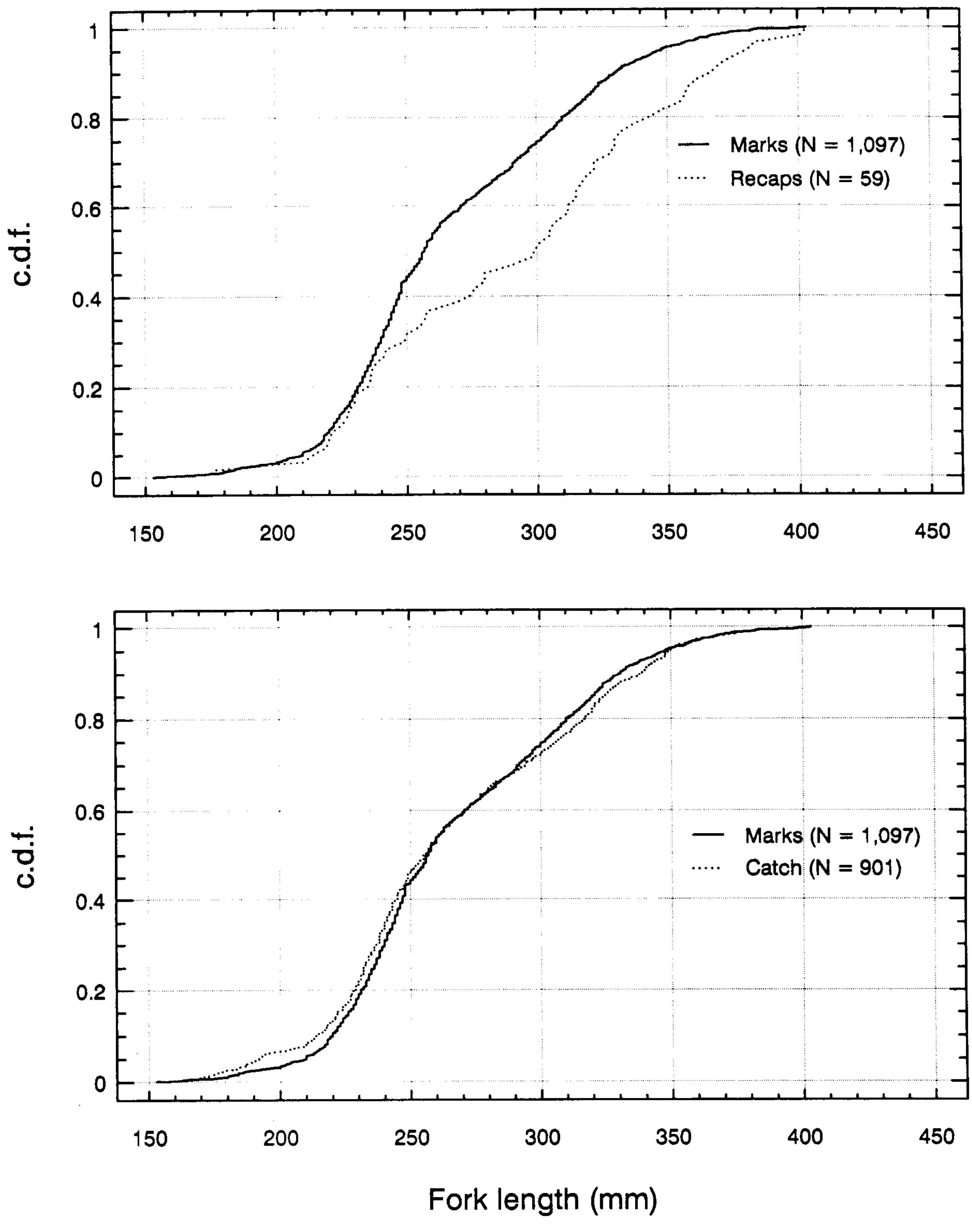

Figure 6. Cumulative density functions (c.d.f.) of fork length of Arctic grayling marked, captured, and recaptured in the Upper Chena section of the Chena River, 22 July through 1 August 1991.

Table 5. Capture probabilities and estimated abundance in two size categories used for population estimation of Arctic grayling (≥ 150 mm FL) in the Upper Chena section of the Chena River, 22 July through 1 August 1991.

Length Category	Mark n_1	Catch n_2	Recap m	ρ[a]	SE[ρ][b]	N[c]	SE[N][d]
150 to 297 mm	803	644	28	0.04	<0.01	17,860	3,186
≥ 298 mm	294	257	31	0.10	0.02	2,370	386
Total	1,097	901	59	---	---	20,230	3,210

[a] ρ is the probability of capture determined from bootstrap methods.
[b] SE[ρ] is the standard error of ρ determined from bootstrap methods.
[c] N is the estimated abundance in a length category.
[d] SE[N] is the standard error of N.

Table 6. Estimates of adjusted age composition and abundance by age class with standard errors for Arctic grayling (≥ 150 mm FL) captured by pulsed-DC electrofishing from the Upper Chena section of the Chena River, 22 through 25 July 1991.

	Age Composition				Abundance		
Age	n[a]	p[b]	SE[c]	CV[d]	N[e]	SE[f]	CV[g]
2	26	0.03	0.01	20.3	644	165	25.5
3	63	0.08	0.01	12.7	1,593	322	20.2
4	485	0.59	0.02	3.4	11,933	1,937	16.2
5	109	0.11	0.01	5.5	2,319	389	16.8
6	98	0.07	0.01	9.9	1,454	271	18.6
7	98	0.06	0.01	18.1	1,298	310	23.9
8	70	0.04	0.01	19.8	741	187	25.2
9	11	<0.01	<0.01	33.0	99	36	36.2
10	13	0.01	<0.01	48.6	120	61	50.5
11	3	<0.01	<0.01	62.7	29	18	63.9
Total	976	1.000	---	---	20,230	3,210	15.9

[a] n = number of Arctic grayling sampled at age.
[b] p = estimated adjusted proportion of Arctic grayling at age in the population. Calculated with bootstrap methods (Efron 1982).
[c] SE = estimated standard error of p. Calculated with bootstrap methods (Efron 1982).
[d] CV = coefficient of variation of p, expressed as a percentage of p.
[e] N = estimated population abundance of Arctic grayling at age.
[f] SE = estimated standard error of N (Seber 1982).
[g] CV = coefficient of variation of N, expressed as a percentage of N.

Table 7. Estimates of age composition and abundance by age with standard errors for Arctic grayling captured by pulsed-DC electrofishing from the Lower and Upper Chena sections and the Chena River, 1991.

	Lower Chena[a]				Upper Chena[b]				Chena River[c]			
Age	p[d]	SE[e]	N[f]	SE[g]	p	SE	N	SE	p	SE	N	SE
2	0.22	0.04	1,455	297	0.03	0.01	644	165	0.08	0.01	2,099	340
3	0.20	0.02	1,290	177	0.08	0.01	1,593	322	0.11	0.01	2,882	368
4	0.30	0.02	1,958	252	0.59	0.02	11,933	1,937	0.52	0.02	13,892	1,953
5	0.10	0.01	647	111	0.11	0.01	2,319	389	0.11	0.01	2,965	404
6	0.06	0.01	391	72	0.07	0.01	1,454	271	0.07	0.01	1,845	280
7	0.07	0.01	456	76	0.06	0.01	1,298	310	0.06	0.01	1,754	319
8	0.04	0.01	261	50	0.04	0.01	741	187	0.04	0.01	1,002	193
9	0.01	<0.01	46	13	<0.01	<0.01	99	36	<0.01	<0.01	145	38
10	<0.01	<0.01	23	9	0.01	<0.01	120	61	<0.01	<0.01	143	62
11	0	0	0	0	<0.01	<0.01	29	18	<0.01	<0.01	29	18
Totals	1.000	---	6,526	701	1.00	---	20,230	3,210	1.00	---	26,756	3,286

[a] Lower Chena section - River kilometer 0 to 72.0.
[b] Upper Chena section - River kilometer 72.0 to 152.0.
[c] Chena River - River kilometer 0 to 152.0.
[d] p = estimated proportion of Arctic grayling at age in the section.
[e] SE = estimated standard error of p.
[f] N = estimated population abundance of Arctic grayling at age in the section.
[g] SE = estimated standard error of N.

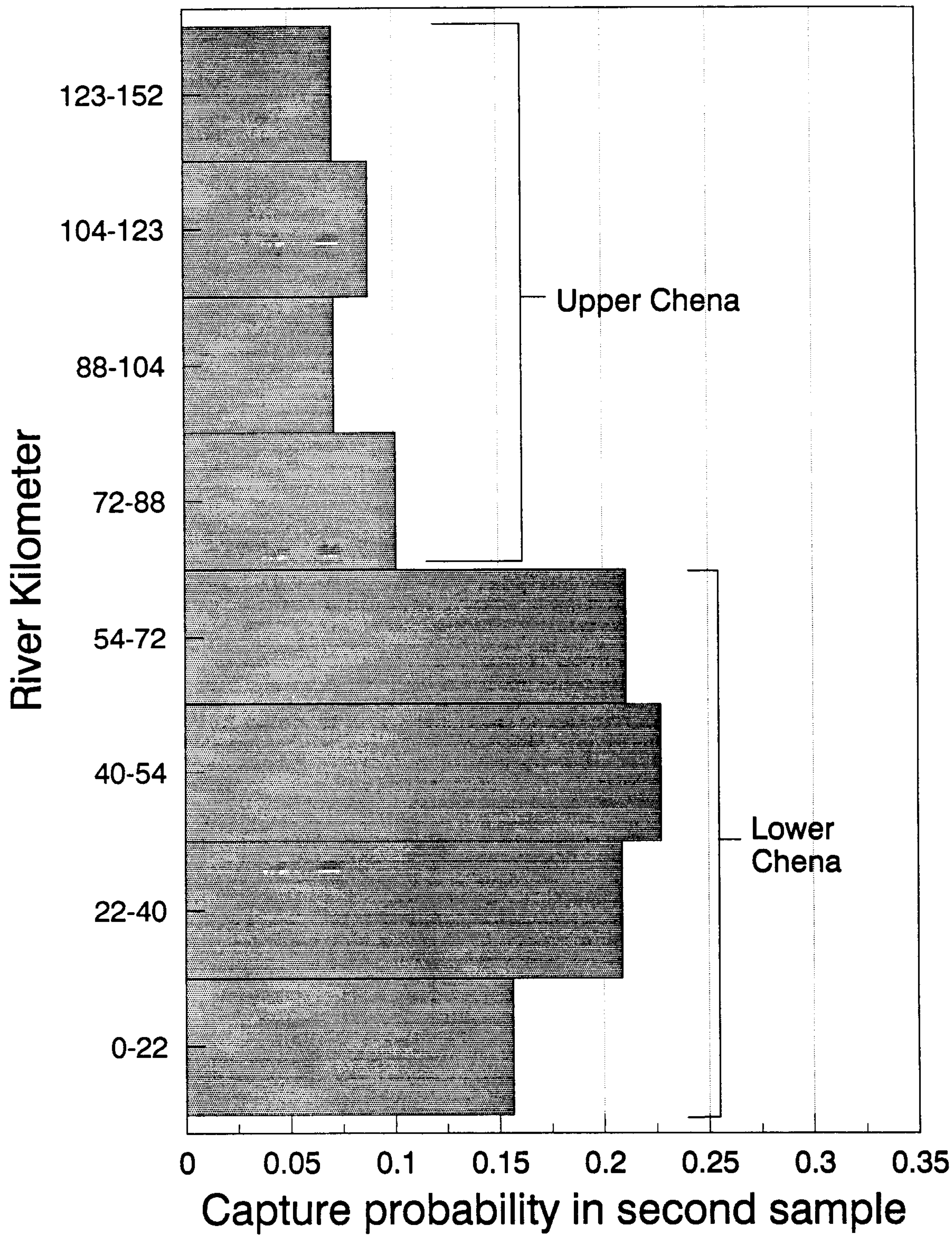

Figure 7. Recapture-to-catch ratios of Arctic grayling (≥ 150 mm FL) in eight reaches of the Chena River in 1992.

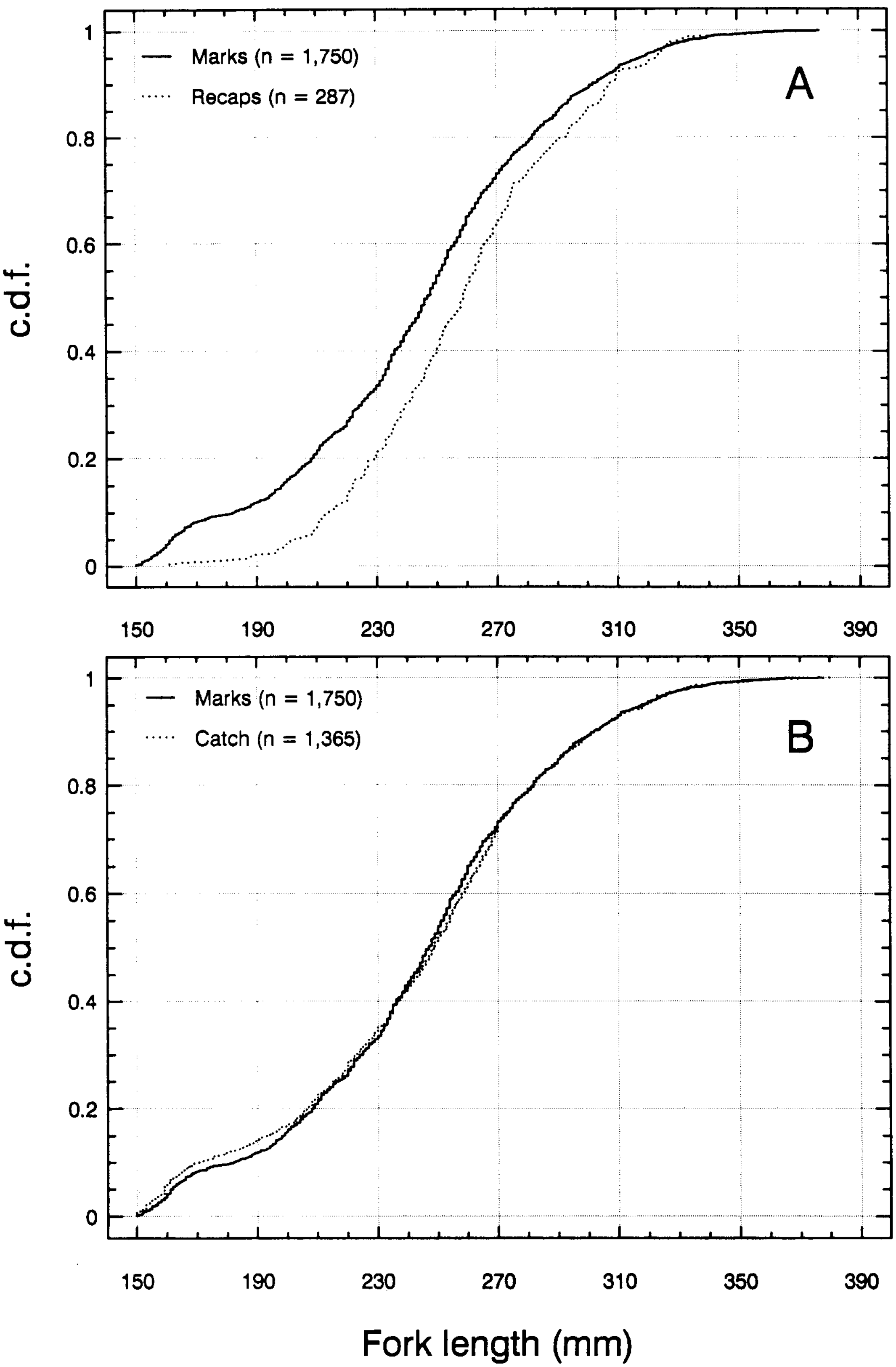

Figure 8. Cumulative density functions (c.d.f.) of fork length of Arctic grayling marked, captured, and recaptured in the Lower Chena section of the Chena River, 6 through 16 July 1992.

Table 8. Capture probabilities and estimated abundance in two size categories used for population estimation of Arctic grayling (≥ 150 mm FL) in the Lower Chena section of the Chena River, 6 through 16 July 1992.

Length Category	Mark n_1	Catch n_2	Recap m	ρ[a]	SE[ρ][b]	N[c]	SE[N][d]
150 to 208 mm	352	289	17	0.05	0.01	5,671	1,260
≥ 209 mm	1,404	1,082	270	0.19	0.01	5,611	294
Total	1,756	1,371	287	---	---	11,316[e]	1,294

[a] ρ is the probability of capture determined from bootstrap methods.
[b] SE[ρ] is the standard error of ρ determined from bootstrap methods.
[c] N is the estimated abundance in a length category.
[d] SE[N] is the standard error of N.
[e] Total abundance is the sum of abundance estimates in each length category (11,282 fish) plus the number of mortalities during the marking event (34 fish).

Table 9. Estimates of adjusted age composition and abundance by age class with standard errors for Arctic grayling (≥ 150 mm FL) captured by pulsed-DC electrofishing from the Lower Chena section of the Chena River, 6 through 9 July 1992.

	Age Composition				Abundance		
Age	n[a]	p[b]	SE[c]	CV[d]	N[e]	SE[f]	CV[g]
2	136	0.22	0.04	17.0	2,521	515	20.4
3	255	0.28	0.02	8.7	3,224	463	14.4
4	301	0.15	0.02	11.3	1,679	269	16.0
5	449	0.19	0.02	11.7	2,208	360	16.3
6	134	0.06	0.01	19.6	633	143	22.6
7	90	0.04	0.01	20.8	426	101	21.1
8	82	0.03	0.01	23.6	378	99	26.2
9	34	0.01	<0.01	25.1	171	47	27.5
10	11	<0.01	<0.01	26.5	53	15	28.3
11	3	<0.01	<0.01	47.9	17	8	47.1
12	1	<0.01	<0.01	110.3	4	5	125.0
Total	1,496	1.000	---	---	11,316	1,294	11.4

[a] n = number of Arctic grayling sampled at age.
[b] p = estimated adjusted proportion of Arctic grayling at age in the population. Calculated with bootstrap methods (Efron 1982).
[c] SE = estimated standard error of p. Calculated with bootstrap methods (Efron 1982).
[d] CV = coefficient of variation of p, expressed as a percentage of p.
[e] N = estimated population abundance of Arctic grayling at age.
[f] SE = estimated standard error of N (Seber 1982).
[g] CV = coefficient of variation of N, expressed as a percentage of N.

very few fish older than age 9 in the Lower Chena. Similarly, stock size fish comprised 83% of abundance in the Lower Chena while only 1% of fish in the Lower Chena were of preferred size (Table 10).

The Upper Chena experiment was performed during 21 through 30 July 1992. A total of 1,363 fish was marked, 1,375 fish was examined for marks, and 115 fish was recaptured during mark-recapture sampling. Fourteen immediate mortalities or serious injuries were recorded for an overall injury rate of 0.5%. Recapture-to-catch ratios did not vary significantly among four areas of the Upper Chena (χ^2 = 0.91, df = 3, P = 0.82; Figure 7). There was a significant change in capture probability by size in Upper Chena section (D = 0.23, $P \approx 2.70 \times 10^{-5}$; Figure 9). However, there was no functional difference in the length frequency of fish marked versus fish examined for marks (D = 0.09, $P \approx 3.22 \times 10^{-5}$; Figure 9). The experiment was stratified into small (150 to 268 mm FL) and large (greater than 268 mm FL) size classes (Table 11). The summed estimate of abundance in the Upper Chena section was 18,033 fish (SE = 1,950 fish). If mark-recapture were not stratified by size, the resulting estimate of abundance would have been 16,168 fish with a bias of 12.5% (see also Appendix B1).

Age 5 fish were also most abundant in the Upper Chena section, accounting for 50% of abundance (Table 12). Ages 3 through 5 comprised 78% of abundance, with very few fish older than age 9 in the Upper Chena. Stock size fish comprised 75% of abundance, while only 3% of fish in the Upper Chena were of preferred size (Table 10).

Estimated abundance of Arctic grayling (≥ 150 mm FL) in the lower 152 km of the Chena River in 1992 was 29,349 fish (SE = 2,341 fish). Age 5 fish represented 38% of the Arctic grayling population (Table 13). Stock size fish accounted for 78% of the population (Table 10). Abundance of age 3 and older Arctic grayling was 25,211 fish (SE = 1,333 fish; Table 14). Survival rate of age 3 and older fish from 1991 to 1992 was 0.79 (SE = 0.08). Recruitment from 1991 to 1992 (age 3 fish) was 5,773 fish (SE = 591 fish). Data files used to estimate abundance, and age and size composition are listed in Appendix C1.

Egg Take and Fingerling Rearing

A total of 163 female and 207 male Arctic grayling were collected during 14 through 20 May 1992. Of these fish, eggs were taken from 67 females and sperm were taken from approximately 150 males. Average number of eggs/ml volume was 28 (SD = 2 eggs/ml). Average fecundity was 3,090 eggs per female (SD = 1,917 eggs) as determined from 49 of the females. A total of approximately 206,000 fertilized eggs were taken, of which 114,500 survived to hatching (D. Parks, Alaska Department of Fish and Game, Clear Hatchery, personal communication). Subsequent mortality reduced the number of fry to 109,500 fish at a weight of 0.5 g per fry. Water temperature ranged from 1.8°C to 3.4°C during collection of fish. Water temperature ranged from 2.0°C to 7.5°C during the taking of eggs.

On 30 July, 33,868 0.5 g fry were transported from Clear Hatchery to the pen rearing facility. Surface water temperature at the facility was 20.0°C on the day of stocking. Average length of fry was 38 mm FL and average weight of fry

Table 10. Summary of Relative Stock Density (RSD) indices of Arctic grayling (≥ 150 mm FL) captured in the Lower and Upper Chena sections, and the Chena River, 1992.

	RSD Category[a]				
	Stock	Quality	Preferred	Memorable	Trophy
<u>Lower Chena</u>					
Number sampled	1,270	462	24	0	0
RSD	0.72	0.26	0.02	0.00	0.00
Adjusted RSD[b]	0.83	0.16	0.01	0.00	0.00
Standard Error	0.02	0.02	<0.01	0.00	0.00
Abundance	9,394	1,823	98	0	0
Standard Error	1,108	337	19	0	0
<u>Upper Chena</u>					
Number sampled	798	487	78	0	0
RSD	0.58	0.36	0.06	0.00	0.00
Adjusted RSD[b]	0.75	0.22	0.03	0.00	0.00
Standard Error	0.03	0.03	0.01	0.00	0.00
Abundance	13,495	3,942	596	0	0
Standard Error	1,570	633	134	0	0
<u>Chena River</u>					
Number sampled	2,068	949	102	0	0
RSD	0.66	0.31	0.03	0.00	0.00
Adjusted RSD[b]	0.78	0.20	0.02	0.00	0.00
Standard Error	0.04	0.02	<0.01	0.00	0.00
Abundance	22,890	5,765	694	0	0
Standard Error	1,921	717	135	0	0

[a] Minimum lengths for RSD categories are (Gabelhouse 1984): stock - 150 mm FL; quality - 270 mm FL; preferred - 340 mm FL; memorable - 450 mm FL; and, trophy - 560 mm FL.

[b] Adjusted RSD is the RSD corrected for differential vulnerability by length from electrofishing. The adjustment is made with bootstrapping methods (Efron 1982). Standard error of RSD is for the adjusted estimate.

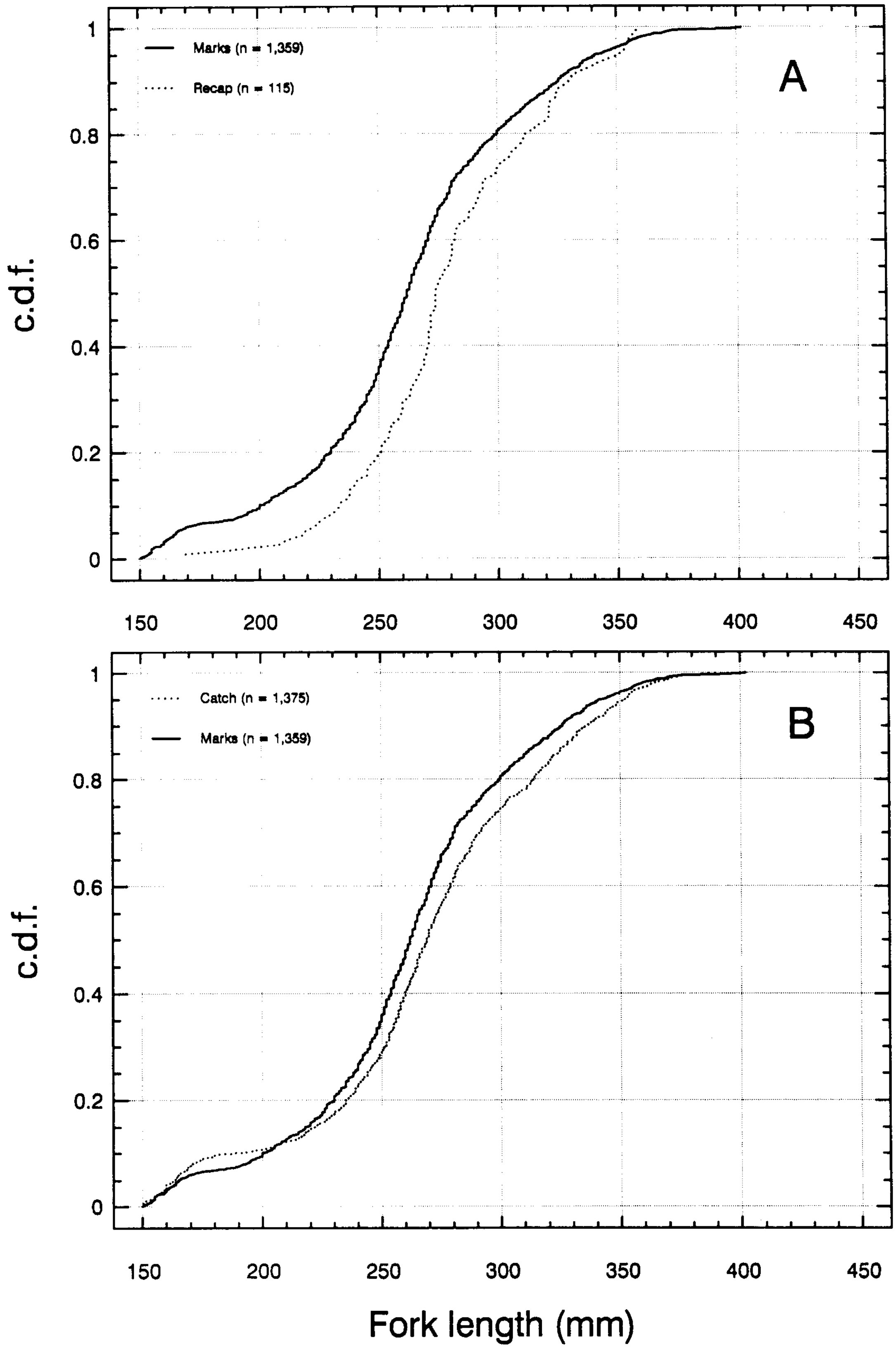

Figure 9. Cumulative density functions (c.d.f.) of fork length of Arctic grayling marked, captured, and recaptured in the Upper Chena section of the Chena River, 21 through 30 July 1992.

Table 11. Capture probabilities and estimated abundance in two size categories used for population estimation of Arctic grayling ($\geq$ 150 mm FL) in the Upper Chena section of the Chena River, 21 through 30 July 1992.

Length Category	Mark n_1	Catch n_2	Recap m	ρ[a]	SE[ρ][b]	N[c]	SE[N][d]
150 to 268 mm	781	676	41	0.05	0.01	12,589	1,859
$\geq$ 269 mm	582	699	74	0.12	0.01	5,432	589
Total	1,363	1,375	115	---	---	18,033[e]	1,950

[a] ρ is the probability of capture determined from bootstrap methods.
[b] SE[ρ] is the standard error of ρ determined from bootstrap methods.
[c] N is the estimated abundance in a length category.
[d] SE[N] is the standard error of N.
[e] Total abundance is the sum of abundance estimates in each length category (18,021 fish) plus the number of mortalities during the marking event (12 fish).

Table 12. Estimates of adjusted age composition and abundance by age class with standard errors for Arctic grayling (≥ 150 mm FL) captured by pulsed-DC electrofishing from the Upper Chena section of the Chena River, 21 through 24 July 1992.

	Age Composition				Abundance		
Age	n[a]	p[b]	SE[c]	CV[d]	N[e]	SE[f]	CV[g]
2	82	0.09	0.01	8.1	1,616	218	13.5
3	125	0.14	0.01	9.7	2,549	369	14.5
4	143	0.14	0.01	5.7	2,623	320	12.2
5	587	0.50	0.02	3.3	8,970	1,015	11.3
6	78	0.04	<0.01	10.3	816	122	14.9
7	67	0.03	0.01	18.6	618	132	21.4
8	51	0.03	0.01	19.9	511	115	22.6
9	23	0.01	<0.01	23.9	202	53	26.1
10	8	<0.01	<0.01	49.9	79	40	50.8
11	3	<0.01	<0.01	52.1	28	15	53.0
12	2	<0.01	<0.01	65.1	21	13	65.6
Total	1,169	1.000	---	---	18,033	1,950	10.8

[a] n = number of Arctic grayling sampled at age.
[b] p = estimated adjusted proportion of Arctic grayling at age in the population. Calculated with bootstrap methods (Efron 1982).
[c] SE = estimated standard error of p. Calculated with bootstrap methods (Efron 1982).
[d] CV = coefficient of variation of p, expressed as a percentage of p.
[e] N = estimated population abundance of Arctic grayling at age.
[f] SE = estimated standard error of N (Seber 1982).
[g] CV = coefficient of variation of N, expressed as a percentage of N.

Table 13. Estimates of age composition and abundance by age with standard errors for Arctic grayling captured by pulsed-DC electrofishing from the Lower and Upper Chena sections and the Chena River, 1992.

	Lower Chena[a]				Upper Chena[b]				Chena River[c]			
Age	p[d]	SE[e]	N[f]	SE[g]	p	SE	N	SE	p	SE	N	SE
2	0.22	0.04	2,521	515	0.09	0.01	1,616	218	0.14	0.02	4,138	559
3	0.28	0.02	3,224	463	0.14	0.01	2,549	369	0.20	0.01	5,773	591
4	0.15	0.02	1,679	269	0.14	0.01	2,623	320	0.15	0.01	4,302	418
5	0.19	0.02	2,208	360	0.50	0.02	8,970	1,015	0.38	0.02	11,179	1,077
6	0.06	0.01	633	143	0.04	<0.01	816	122	0.05	<0.01	1,450	188
7	0.04	0.01	426	101	0.03	0.01	618	132	0.04	<0.01	1,044	166
8	0.03	0.01	378	99	0.03	0.01	511	115	0.03	<0.01	889	152
9	0.01	<0.01	171	47	0.01	<0.01	202	53	0.01	<0.01	373	71
10	<0.01	<0.01	53	15	<0.01	<0.01	79	40	<0.01	<0.01	132	43
11	<0.01	<0.01	17	8	<0.01	<0.01	28	15	<0.01	<0.01	45	17
12	<0.01	<0.01	4	5	<0.01	<0.01	21	13	<0.01	<0.01	25	14
Totals	1.000	---	11,316	1,294	1.00	---	18,033	1,950	1.00	---	29,349	2,341

[a] Lower Chena section - River kilometer 0 to 72.0.
[b] Upper Chena section - River kilometer 72.0 to 152.0.
[c] Chena River - River kilometer 0 to 152.0.
[d] p = estimated proportion of Arctic grayling at age in the section.
[e] SE = estimated standard error of p.
[f] N = estimated population abundance of Arctic grayling at age in the section.
[g] SE = estimated standard error of N.

Table 14. Summary of population abundance, annual survival (%), annual recruitment, and standard error estimates during 1986-1992 for Arctic grayling (≥ age 3) in the lower 152 km of the Chena River.

Year	Abundance	SE	Survival	SE	Recruitment	SE
1986[a]	61,581	26,987				
			43.9	20.1	2,526	358
1987[a]	29,580	3,525				
			57.1	8.1	3,373	529
1988[a]	20,268	1,214				
			58.7	9.0	4,332	491
1989[a]	16,236	1,618				
			75.4	11.0	16,881	4,172
1990[a]	29,130	4,373				
			74.7	13.2	2,882	368
1991	24,657	2,082				
			78.8	8.2	5,773	591
1992	25,211	1,333				

[a] Source document for parameter estimates in these years is Clark (1991).

was 0.51 g. During the 42 day rearing period, fry were fed approximately 114,550 g of commercial feed and gained 45,364 g in total biomass. Water temperature averaged 16.1, 14.5, and 10.8°C at depths of 0.1, 1.8, and 3.6 m below the surface. There were 4,717 observed mortalities of fry during the rearing period, although some of the dead fry likely passed through the meshes of the pen.

Fin clipping was performed on 2 through 4 September and 23,199 fingerlings were enumerated. On 11 September 7,941 fingerlings were released into the Chena River at river kilometer 116.8 (adjacent to an access road at kilometer 44.8 of the Chena Hot Springs Road; Figure 4). An additional 7,317 fingerlings were released at river kilometer 72.0 (Moose Creek Dam complex). The remaining 7,941 fingerlings were released at river kilometer 40.0 (Nordale Road crossing). Average length of fingerlings was 65 mm FL and average weight was 2.7 g at the time of release. Water temperature at the release sites was 4.4°C. Further details of rearing and release were summarized in Appendix D.

DISCUSSION

Sample Design

Although the overall precision of abundance estimates in the lower 152 km of the Chena River has not changed since 1987, precision of abundance estimates in the Lower Chena section has improved markedly since 1990. In 1991, the sample design for the Lower Chena section was changed from an expansion of estimates performed in 3.2 km long areas (see Clark and Ridder 1987b) to a single-sample mark-recapture design that had been used in the Upper Chena section since 1987. During the four year period from 1987 to 1990, average CV of abundance in the Lower Chena was 21.2% (range: 12.0% to 37.3%). In 1991 and 1992, average CV of abundance in this same section was 11.0% (range: 10.7% to 11.4%). Since crewpower to perform the Lower Chena experiment was increased 100% (increased from 24 to 48 crewdays) and the resulting benefit was a 92% decrease in CV, the benefit-cost ratio was approximately 96%.

However, there was only a slight change in CV of abundance of the entire Chena River during these two time periods (CV averaged 11.0% during 1987 through 1990, and averaged 10.1% during 1991 and 1992). The reason for this is that variance of abundance in the Upper Chena, on average, accounts for 64.2% of the total variance (range: 5.2% to 95.4%) and the CV of abundance in the Upper Chena was lower during 1987 through 1990 than in 1991 and 1992 (CV averaged 9.4% during 1987 through 1990, and averaged 13.3% during 1991 and 1992). Moreover, a 0.9% change in CV of abundance in the Chena River represents a change in SE of 241 fish and a change in variance of 58,073.

Stock Status

During the past seven years (1986 through 1992) annual recruitment and annual survival rate have been estimated from population abundance and age composition data. Estimates of recruitment during the period indicate continual low recruitment, with one year of moderate recruitment out of six years (Table 14). Based on the historic average of recruitment in the Chena

River (13,425 fish; Clark 1992a), recruitment during 1986 through 1992 was below average in all but one year. Moreover, recruitment in 1987 and in 1991 were the lowest and second lowest, respectively, since 1979. However, estimates of survival have increased since regulatory measures were taken in 1987. This is fortuitous because the observed levels of recruitment have been insufficient to replace losses that might have occurred had regulatory measures not been taken. Although abundance appears to have stabilized at approximately 27,000 fish, this has come at the cost of reduced fishing mortality and loss of opportunity for anglers to harvest Arctic grayling from the Chena River.

Regulatory measures were taken in June of 1991 to prohibit the harvest of Arctic grayling from the Chena River. Therefore, survival rate during 1991 through 1992 can be used as an estimate of annual natural mortality (1 - survival rate). Annual natural mortality rate for 1991 through 1992 was 21.2% (100% - 78.8%), which is comparable to the average estimate of natural mortality for the Chena River during 1979 through 1988 of 21.7% (reported by Clark 1992a). This estimate is also comparable to that of Clark (*In prep*) for Arctic grayling in Fielding Lake during 1986 through 1990 (annual natural mortality rate of 19.4%). It appears that natural mortality rates are similar for these two stocks of Arctic grayling and that differences in maximum age (12 years for the Chena River and 10 years for Fielding Lake) may be due to differences in abundance of year classes (e.g., 5,000 fish at age 6 in the Chena River and 1,600 fish at age 6 in Fielding Lake).

<u>Egg Take and Fingerling Rearing</u>

Rehabilitation of the Chena River stock was initiated with an egg take and fingerling rearing and release program in 1992. In terms of the number of fertilized eggs taken and number of fry surviving to 0.5 g, the egg take was successful. However, problems were encountered during the egg take that could be alleviated in 1993. All fish were examined for maturity by expression of gametes. There appeared to be no problems encountered when this method was used on female fish. When males were examined with this method, some of the mature fish failed to subsequently give milt when needed for fertilization of eggs.

The second problem encountered was that female fish had to be held up to 28 days before ripening of the eggs. The effect of holding on these fish was: 1) some females developed a "plug" of water hardened eggs that made expression of eggs difficult; 2) most females showed visible signs of stress (eroded fins and snout, abrasion and extreme swelling of the vent); and, 3) females spawned on 10 June had bloody and nonviable eggs. The "plug" of water hardened eggs may have occurred because of the frequent examination for ripeness; some water enters the egg mass when the fish is checked and hardens some of the eggs (D. Parks, Alaska Department of Fish and Game, Clear Hatchery, personal communication).

Most of the problems encountered during the egg take could be alleviated by not examining male fish until the day of the egg take and less frequent examination of female fish for ripeness. However, the major factor influencing the success of the egg take may have been persistent low water temperature (<8°C) during the holding period. Some studies have shown that viability of rainbow trout *Oncorhynchus mykiss* eggs is decreased by extended periods of holding (Sakai et al. 1975, Bry 1981). This may explain why female Arctic grayling held for as many as 28 days had nonviable eggs. If water temperature remains low for an extended period in 1993, transportation of fish to warmer water (a borrow pond or slough) may be warranted.

Average fecundity of female fish in 1992, although useful for planning the egg take in 1993, is insufficient information for research purposes. Female fish will be individually spawned in 1993 to increase sample size for modeling the fecundity at size and fecundity at age relations. Although little fecundity information exists for Arctic grayling, the average fecundity of fish from the Chena River was comparable to fecundity of fish from the Goodpaster River (3,404 eggs/female; Holmes et al. 1986), but less than fecundity of fish from Fielding Lake (~5,500 eggs/female; Warner 1955) and from Moose Lake in the Copper River drainage (~4,000 eggs/female; D. Parks, Alaska Department of Fish and Game, Clear Hatchery, personal communication).

Late arrival of 0.5 g fry (30 July) and cooler than normal water temperature in the borrow pond were major factors influencing the smaller than expected size (65 mm) of fingerlings at release. If collection of fertilized eggs is facilitated by warmer water temperature, fry will reach 0.5 g sooner in the summer (15 July), and the rearing period will be extended. An experiment conducted in 1991 showed that 0.5 g fry (39 mm FL), reared in a similar net pen for 60 days in the same borrow pond used in 1992, grew to 94 mm FL (C. Skaugstad, Alaska Department of Fish and Game, Fairbanks, personal communication).

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APPENDIX A
Historic Data Summary

Appendix A1. Source citations for Federal Aid and Fishery Data Reports used for data summaries, 1955-1958 and 1967-1992.

Year	Type of Data[a]	Source Document
1955	CC	Warner (1959)
1956	CC	Warner (1959)
1957	CC	Warner (1959)
1958	CC	Warner (1959)
1967	AL, CC, POP	Van Hulle (1968)
1968	AL, CC, POP	Roguski and Winslow (1969)
1969	AL, CC, POP	Roguski and Tack (1970)
1970	CC, POP	Tack (1971)
1971	POP	Tack (1972)
1972	CC, POP	Tack (1973)
1973	AL, POP	Tack (1974)
1974	AL, CC, POP	Tack (1975)
1975	AL, CC, POP	Tack (1976)
1976	AL, CC, POP	Hallberg (1977)
1977	AL, CC, POP	Hallberg (1978)
1978	AL, CC, POP	Hallberg (1979)
1979	AL, CC, POP	Hallberg (1980)
1980	AL, CC, POP	Hallberg (1981)
1981	AL, CC, POP	Hallberg (1982)
1982	AL, CC, POP	Holmes (1983)
1983	AL, CC, POP	Holmes (1984)
1984	AL, CC, POP	Holmes (1985)
1985	AL, CC, POP	Holmes et al. (1986)
1986	CC	Clark and Ridder (1987a)
	AL, POP	Clark and Ridder (1987b)
1987	CC	Baker (1988)
	AL, POP	Clark and Ridder (1988)
1988	CC	Baker (1989)
	AL, POP	Clark (1989)
1989	CC	Merritt et al. (1990)
	AL, POP	Clark (1990)
1990	AL, POP	Clark (1991)
1991	AL, POP	Clark (this report)
	CC	Hallberg and Bingham (1992)
1992	AL, POP	Clark (this report)

[a] CC = Creel census estimates;
AL = age and size composition estimates; and,
POP = population abundance estimates.

Appendix A2. Chena River study sections used from 1968 to 1985[a].

Section Number	Section Name	River Kilometers	Length in Kilometers
1	River mouth to University Ave.	0-9.6	9.6
2A	University Ave. to Peger Road	9.6-12.8	3.2
2B	Peger Road to Wendell Street	12.8-17.6	4.8
3	Wendell St. to Wainwright Bridge	17.6-23.2	5.6
4	Wainwright Bridge to Badger Slough	23.2-34.4	11.2
5	Badger Slough		26.4
6	Badger Slough to Little Chena R.	34.4-39.2	4.8
7	Little Chena River		98.4
8	Little Chena to Nordale Slough	39.2-49.6	10.4
DS	Nordale Slough to Bluffs	49.6-88.8	39.2
9B	Bluffs to Bailey Bridge	88.8-100.8	12.0
10	Bailey Bridge to Hodgins Slough	100.8-126.4	25.6
11	Hodgins Slough to 90 Mi. Slough	126.4-144.0	17.6
12	90 Mi. Slough to First Bridge	144.0-147.2	3.2
13	First Bridge to Second Bridge	147.2-151.2	4.0
14	Second Bridge to North Fork	151.2-163.2	12.0
15	North Fork of Chena River		56.0
16	East Fork of Chena River		99.2
17	West Fork of Chena River		56.0

[a] Taken from Hallberg 1980.

Appendix A3. Summary of population abundance estimates of Arctic grayling ($\geq$ 150 mm FL) in the Chena River, 1968-1992.

Year	Dates	Area[a]	Estimator[b]	Estimate	Confidence[c]
1968	Summer?	2	SN	411/km	393-1,209
	Summer?	6	SN	283/km	228-381
1969	June?	2	SN	596/km	474-850
	June?	6	SN	571/km	439-816
1970	7/02-7/10	2	SN	919/km	690-1,519
	5/26-5/30	6	SN	373/km	346-408
	6/08-7/08	9B	SN	1,005/km	803-1,411
	6/07-7/07	10	SN	1,171/km	876-1,957
1971	8/30-9/03	2A	SN	300/km	192-1,157
	6/02-6/07	2B	SN	1,302/km	958-2,305
	8/30-9/03	2B	SN	2,338/km	1,753-3,897
	6/21-6/24	6	SN	189/km	161-233
1972	6/22-6/26	2A	SN	309/km	236-489
	6/22-6/26	2B	SN	608/km	493-828
	6/19-6/20	6	SN	159/km	124-235
	6/27-6/29	DS	SN	812/km	604-1,393
1973	7/10-7/13	2A	SN	293/km	218-502
	7/03-7/14	2B	SN	424/km	354-545
	7/16-7/17	6	SN	243/km	203-312
	7/18-7/19	DS	SN	500/km	379-806
1974	6/26-6/28	2A	SE	65/km	36-372
	6/25-6/28	2B	SE	488/km	207-1,378
	8/13-8/15	6	SE	100/km	71-164
	7/09-7/11	DS	SE	263/km	221-326
1975	7/10-7/14	6	SE	191/km	114-589
1976	7/19-7/21	2A	SE	258/km	223-307
	7/22-7/24	2B	SE	409/km	323-556
	7/28-7/30	6	SE	163/km	153-175
	8/04-8/06	DS	SE	306/km	285-329
1977	7/05-7/08	2A	SE	318/km	298-343
	7/11-7/14	2B	SE	318/km	280-370
	7/18-7/21	6	SE	173/km	170-177
	7/26-7/30	DS	SE	315/km	283-359
1978	7/14-7/17	2A	SE	69/km	44-156
	7/25-7/28	2B	SE	162/km	148-179
	7/10-7/13	6	SE	226/km	210-243
	8/08-8/11	DS	SE	345/km	333-359

- continued -

Appendix A3. (Page 2 of 2).

Year	Dates	Area[a]	Estimator[b]	Estimate	Confidence[c]
1979	7/01-7/03	2A	SE	57/km	45-76
	6/26-6/30	2B	SE	201/km	188-216
	8/20-8/23	8A	SE	177/km	161-197
	7/17-7/20	DS	SE	193/km	144-288
1980	7/01-7/04	2B	SE	308/km	229-471
	7/14-7/17	8A	SE	190/km	154-248
	7/29-8/01	DS	SE	236/km	200-287
	8/12-8/15	10B	SE	842/km	640-1,234
1981	8/07-8/10	2B	SN	262/km	223-392
	8/03-8/06	8A	SN	224/km	164-309
	8/11-8/14	DS	SN	302/km	174-440
	7/21-7/24	10B	SN	869/km	466-1,778
1982	7/16-7/20	2B	SN	116/km	79-177
	7/13-7/15	8A	SN	87/km	60-132
	7/23-7/27	DS	SN	232/km	113-579
	7/28-7/30	10B	SN	875/km	529-1563
1983	7/13-7/15	2B	SN	216/km	168-265
	7/05-7/07	8A	SN	119/km	81-545
	7/8,7/11-7/12	DS	SN	209/km	149-303
	7/26-7/28	10B	SN	911/km	647-1,338
	7/19-7/21	12	SN	208/km	138-332
1984	7/16-7/18	2B	SN	211/km	167-268
	7/3,7/05-7/06	8A	SN	139/km	95-215
	7/09-7/11	DS	SN	179/km	124-273
	7/19-7/20	10B	P	493/km	275-1,003
	7/31,8/02-8/03	12	SN	1,318/km	449-6,592
1985	7/10-7/17	2B	SN	189/km	92-287
	6/26-7/02	8A	SN	271/km	189-360
	7/03-7/08	DS	SN	333/km	234-432
	7/22-7/31	10B	SN	1,156/km	304-3,035
	6/12-6/24	12	SN	1,092/km	552-1,643
1986	7/07-8/06	WC	EXP	61,581 (405/km)	SE = 26,987
1987	6/27-7/30	WC	EXP+P	31,502 (207/km)	SE = 3,500
1988	6/26-8/04	WC	EXP+P	22,204 (146/km)	SE = 2,092
1989	7/10-8/03	WC	EXP+P	19,028 (125/km)	SE = 1,578
1990	7/02-8/03	WC	EXP+P	31,815 (209/km)	SE = 4,880
1991	7/08-8/01	WC	P	26,756 (176/km)	SE = 3,286
1992	7/06-7/30	WC	P	29,349 (193/km)	SE = 2,341

[a] Areas are taken from Hallberg (1980); WC = Whole Chena River (lower 152 km).

[b] Estimators are: SN = Schnabel; SE = Schumacher-Eschmeyer; P = Petersen (Ricker 1975); EXP = Expanded estimates (Clark and Ridder 1987b); EXP+P = expanded estimates and a Petersen estimate (Clark and Ridder 1988).

[c] Confidence is either the 95% confidence interval or the standard error (SE) of the estimate.

Appendix A4. Summary of Arctic grayling creel census on the Chena River, 1955-1958, 1967-1970, 1972, 1974-1989, and 1991.

Year	Dates	Area	Angler Hours	Harvest	CPUE	Mean Length
1955	ND	Lower Chena	---	---	0.89	226
1956	ND	Lower Chena	---	---	0.95	251
1957	ND	Lower Chena	---	---	0.62	246
1958	ND	Lower Chena	---	---	0.88	226
1967	4/10 to 8/11	Entire Chena	12,885	---	0.32	245
1968	5/01 to 9/02	Entire Chena	10,269	5,643	0.55	251
1969	7/01 to 9/30	Entire Chena	7,998	7,686	0.96	263
1970	5/01 to 5/30 and 7/01 to 8/31	Entire Chena	12,518	6,770	0.54	---
1972	5/25 to 8/27	Lower Chena	13,116	10,099	0.77	---
1974	7/01 to 8/31	Upper Chena	11,680	18,049	1.72	---
1975	6/01 to 8/31	Upper Chena	22,657	14,067	0.62	252
1976	6/01 to 8/31	Upper Chena	10,762	4,161	0.39	230
1977	6/01 to 8/31	Upper Chena	13,563	9,406	0.71	208
1978	5/29 to 8/31	Upper Chena	10,508	6,898	0.65	222
1979	6/01 to 8/31	Upper Chena	12,564	8,544	0.69	240
1980	5/08 to 9/30	Upper Chena	20,827	16,390	0.78	256
1981	5/01 to 8/31	Upper Chena	15,896	13,549	0.80	---
1982	5/01 to 9/15	Upper Chena	20,379	12,603	0.62	248
1983	5/01 to 9/15	Upper Chena	19,018	10,821	0.58	260
1984	5/06 to 9/15	Upper Chena	17,090	9,623	0.59	278
1985	5/08 to 9/05	Upper Chena	10,613	2,367	0.22	273
1986	5/10 to 9/15	Upper Chena	10,716	3,326	0.31	271
1987	5/18 to 9/15	Upper Chena	9,090	1,260	0.14	290
1988	5/14 to 9/13	Upper Chena	11,763	1,583	0.13	287
1989	5/19 to 9/13	Upper Chena	11,349	3,325	0.21	295
1991	5/18 to 7/31	Upper Chena[a]	3,201	---	---	280

[a] Only road km 43 through 73 of the Chena Hot Springs Road.

Appendix A5. Summary of age composition estimates of Arctic grayling in the Chena River, 1967-1969 and 1973-1992.

	Age 0		Age 1		Age 2		Age 3		Age 4		Age 5		Age 6		Age 7		Age 8		Age 9		Age 10		Age 11	
Year	p[a]	SE[b]	p	SE	p	SE	p	SE	p	SE	p	SE	p	SE	p	SE	p	SE	p	SE	p	SE	p	SE
1967	0.10	0.02	0.13	0.02	0.13	0.02	0.06	0.01	0.17	0.02	0.25	0.02	0.11	0.02	0.05	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1968	0.09	0.03	0.21	0.04	0.24	0.04	0.25	0.04	0.13	0.03	0.03	0.01	0.05	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1969	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.06	0.38	0.07	0.12	0.05	0.16	0.05	0.06	0.03	0.06	0.03	0.00	0.00	0.00	0.00	0.00	0.00
1973	0.00	0.00	0.06	0.02	0.13	0.02	0.61	0.03	0.18	0.03	0.03	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1974	0.00	0.00	0.04	0.01	0.11	0.02	0.12	0.02	0.44	0.03	0.25	0.02	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1975	0.00	0.00	0.00	0.00	0.13	0.04	0.25	0.05	0.13	0.04	0.26	0.05	0.19	0.04	0.02	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1976	0.00	0.00	0.10	0.02	0.24	0.03	0.29	0.03	0.15	0.02	0.09	0.02	0.11	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1977	0.00	0.00	0.06	0.02	0.34	0.03	0.45	0.03	0.08	0.02	0.06	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1978	0.00	0.00	0.15	0.02	0.38	0.03	0.22	0.03	0.21	0.02	0.03	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1979	0.00	0.00	0.11	0.02	0.20	0.03	0.45	0.03	0.17	0.03	0.05	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1980	0.00	0.00	0.02	0.01	0.12	0.02	0.39	0.03	0.28	0.03	0.13	0.02	0.05	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1981	0.00	0.00	0.16	0.02	0.13	0.02	0.40	0.02	0.12	0.02	0.12	0.02	0.06	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1982	0.00	0.00	0.06	0.01	0.30	0.03	0.11	0.02	0.35	0.03	0.09	0.02	0.04	0.01	0.02	0.01	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1983	0.01	0.01	0.07	0.01	0.11	0.01	0.45	0.02	0.08	0.01	0.17	0.02	0.06	0.01	0.03	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1984	0.00	0.00	0.19	0.02	0.07	0.01	0.12	0.02	0.41	0.02	0.08	0.01	0.09	0.01	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1985	0.00	0.00	0.02	0.00	0.16	0.01	0.11	0.01	0.14	0.01	0.32	0.01	0.10	0.01	0.10	0.01	0.04	0.00	0.02	0.00	0.00	0.00	0.00	0.00
1986	0.00	0.00	0.00	0.00	0.00	0.00	0.65	0.01	0.07	0.01	0.09	0.01	0.13	0.01	0.04	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1987	0.00	0.00	0.00	0.00	0.05	0.01	0.08	0.01	0.60	0.03	0.07	0.01	0.05	0.01	0.10	0.02	0.02	0.01	0.02	0.00	0.00	0.00	0.00	0.00
1988	0.00	0.00	0.00	0.00	0.09	0.02	0.15	0.02	0.12	0.02	0.42	0.04	0.07	0.01	0.06	0.01	0.07	0.01	0.02	0.00	0.00	0.00	0.00	0.00
1989	0.00	0.00	0.00	0.00	0.15	0.02	0.23	0.03	0.14	0.02	0.14	0.02	0.22	0.03	0.06	0.01	0.04	0.01	0.03	0.01	0.00	0.00	0.00	0.00
1990	0.00	0.00	0.00	0.00	0.08	0.04	0.53	0.08	0.10	0.03	0.08	0.02	0.07	0.02	0.09	0.02	0.02	0.01	0.01	0.00	<0.01	0.00	<0.01	0.00
1991	0.00	0.00	0.00	0.00	0.08	0.01	0.11	0.01	0.52	0.02	0.11	0.01	0.07	0.01	0.06	0.01	0.04	0.01	<0.01	0.00	<0.01	0.00	<0.01	0.00
1992	0.00	0.00	0.00	0.00	0.14	0.02	0.20	0.01	0.15	0.01	0.38	0.02	0.05	0.00	0.04	0.00	0.03	0.00	0.01	0.00	<0.01	0.00	<0.01	0.00

[a] p = the proportion of the sample at age.
[b] SE = the standard error of p.

Appendix A6. Summary of mean length at age estimates of Arctic grayling from the Chena River, 1967-1969 and 1973-1992.

Year	Age 0		Age 1		Age 2		Age 3		Age 4		Age 5		Age 6		Age 7		Age 8		Age 9		Age 10		Age 11	
	n[a]	FL[b]	n	FL	n	FL	n	FL	n	FL	n	FL	n	FL	n	FL	n	FL	n	FL	n	FL	n	FL
1967	30	25	41	135	41	186	17	243	51	272	77	293	32	321	15	335	0	---	0	---	0	---	0	---
1968	10	73	24	103	28	150	29	214	15	255	3	289	6	304	2	372	0	---	0	---	0	---	0	---
1969	0	---	0	---	0	---	11	191	19	236	6	273	8	304	3	317	3	356	0	---	0	---	0	---
1973	0	---	11	111	25	167	121	194	36	215	6	279	0	---	1	310	0	---	0	---	0	---	0	---
1974	0	---	12	130	32	169	37	199	133	217	76	236	12	259	1	315	0	---	0	---	0	---	0	---
1975	0	---	0	---	12	171	22	200	12	229	23	238	17	258	2	275	1	320	0	---	0	---	0	---
1976	0	---	26	144	61	175	74	194	39	221	24	249	28	270	4	308	0	---	0	---	0	---	0	---
1977	0	---	14	112	77	176	102	208	19	245	13	263	4	299	0	---	0	---	0	---	0	---	0	---
1978	0	---	39	128	102	167	59	206	56	230	9	256	2	290	1	325	0	---	0	---	0	---	0	---
1979	0	---	25	107	44	165	99	197	38	236	11	266	1	310	0	---	0	---	0	---	0	---	0	---
1980	0	---	4	114	31	154	97	198	71	231	33	259	12	292	3	327	0	---	0	---	0	---	0	---
1981	0	---	61	112	48	162	152	187	46	215	47	240	22	268	5	287	3	310	0	---	0	---	0	---
1982	0	---	19	105	88	137	34	190	105	215	26	251	11	279	7	305	6	337	0	---	0	---	0	---
1983	6	62	33	114	53	151	215	177	38	216	83	239	29	273	13	307	7	338	0	---	0	---	0	---
1984	0	---	82	97	32	153	54	182	179	213	36	226	40	257	7	275	6	321	0	---	0	---	0	---
1985	0	---	42	108	300	141	203	188	267	215	609	233	182	285	188	285	80	308	30	377	2	377	0	---
1986	0	---	40	109	104	164	755	184	79	220	110	251	153	270	42	301	22	318	5	330	1	346	0	---
1987	0	---	0	---	54	160	92	204	691	228	115	274	76	292	184	309	30	324	31	338	2	353	0	---
1988	0	---	7	108	135	172	238	216	181	239	707	260	118	288	95	313	110	325	35	347	7	337	2	374
1989	0	---	17	123	285	156	295	215	205	254	245	272	423	285	112	314	73	329	54	347	5	372		
1990	0	---	13	129	134	174	840	207	232	251	223	280	221	298	284	308	63	332	43	340	17	362	2	359
1991	0	---	0	---	143	177	211	215	863	241	227	273	177	298	199	303	135	316	23	335	19	347	3	338
1992	0	---	0	---	224	165	384	209	450	239	1046	262	214	288	157	307	134	312	57	321	20	338	6	347
Average		40		114		159		198		230		255		285		305		323		348		358		366

[a] n = sample size.
[b] FL = the arithmetic mean fork length in millimeters.

Appendix A7. Summary of Relative Stock Density (RSD) indices of Arctic grayling (≥ 150 mm FL) captured by electrofishing from the Chena River, 1972-1992.

	RSD Category[a]				
	Stock	Quality	Preferred	Memorable	Trophy
1972 (2A, 2B, 6, DS) - 6/19-6/22[b]					
Sample size	1,392	42	3	0	0
RSD	0.97	0.03	<0.01	0.00	0.00
Standard Error	0.01	<0.01	<0.01	0.00	0.00
1973 (2A, 2B, 6, DS) - 7/3-7/19					
Sample size	176	7	0	0	0
RSD	0.96	0.04	0.00	0.00	0.00
Standard Error	0.01	0.01	0.00	0.00	0.00
1974 (2A, 2B, 6, DS) - 6/25-8/15					
Sample size	889	58	0	0	0
RSD	0.94	0.06	0.00	0.00	0.00
Standard Error	0.01	0.01	0.00	0.00	0.00
1975 (6) - 7/10-7/14					
Sample size	76	13	0	0	0
RSD	0.85	0.15	0.00	0.00	0.00
Standard Error	0.04	0.04	0.00	0.00	0.00
1976 (2A, 2B, 6, DS) - 7/19-8/6					
Sample size	613	59	1	0	0
RSD	0.91	0.09	<0.01	0.00	0.00
Standard Error	0.01	0.01	<0.01	0.00	0.00
1977 (2A, 2B, 6, DS) - 7/5-7/30					
Sample size	916	30	0	0	0
RSD	0.967	0.03	0.00	0.00	0.00
Standard Error	0.01	0.01	0.00	0.00	0.00
1978 (2A, 2B, 6, DS) - 7/10-8/11					
Sample size	841	20	0	0	0
RSD	0.98	0.02	0.00	0.00	0.00
Standard Error	0.01	0.01	0.00	0.00	0.00

- continued -

	RSD Category[a]				
	Stock	Quality	Preferred	Memorable	Trophy
1979 (2A, 2B, 8A, DS) - 6/26-8/23					
Sample size	802	13	0	0	0
RSD	0.98	0.02	0.00	0.00	0.00
Standard Error	<0.01	<0.01	0.00	0.00	0.00
1980 (2B, 8A, DS, 10B) - 7/1-8/15					
Sample size	1,260	53	2	0	0
RSD	0.96	0.04	<0.01	0.00	0.00
Standard Error	0.01	0.01	<0.01	0.00	0.00
1981 (2B, 8A, DS, 10B) - 7/21-8/14					
Sample size	1,247	42	1	0	0
RSD	0.97	0.03	<0.01	0.00	0.00
Standard Error	<0.01	<0.01	<0.01	0.00	0.00
1982 (2B, 8A, DS, 10B) - 7/13-7/30					
Sample size	919	76	5	0	0
RSD	0.92	0.08	0.01	0.00	0.00
Standard Error	0.01	0.01	<0.01	0.00	0.00
1983 (2B, 8A, DS, 10B, 12) - 7/5-7/28					
Sample size	1,560	152	10	0	0
RSD	0.91	0.09	0.01	0.00	0.00
Standard Error	0.01	0.01	<0.01	0.00	0.00
1984 (2B, 8A, DS, 10B, 12) - 7/3-8/3					
Sample size	1,349	74	4	0	0
RSD	0.95	0.05	<0.01	0.00	0.00
Standard Error	0.01	0.01	<0.01	0.00	0.00
1985 (2B, 8A, DS, 10B, 12) - 6/12-7/31					
Sample size[c]	ND	ND	ND	ND	ND
RSD	---	---	---	---	---
Standard Error	---	---	---	---	---
1986 (lower 152 km) - 7/7-8/6					
Sample size	1,268	160	29	0	0
RSD	0.87	0.11	0.02	0.00	0.00
Standard Error	0.01	0.01	<0.01	0.00	0.00

- continued -

Appendix A7. (Page 3 of 3).

	RSD Category[a]				
	Stock	Quality	Preferred	Memorable	Trophy
1987 (lower 152 km) - 6/27-7/30					
Sample size	1,678	693	154	0	0
RSD	0.67	0.27	0.06	0.00	0.00
Adjusted RSD[d]	0.78	0.19	0.03	0.00	0.00
Standard Error[e]	0.04	0.04	0.01	0.00	0.00
1988 (lower 152 km) - 6/26-8/4					
Sample size[f]	1,855	1,242	217	0	0
RSD	0.63	0.32	0.05	0.00	0.00
Standard Error	0.04	0.03	0.01	0.00	0.00
1989 (lower 152 km) - 7/10-8/3					
Sample size[f]	1,363	1,340	184	0	0
RSD	0.47	0.46	0.06	0.00	0.00
Adjusted RSD[d]	0.57	0.38	0.05	0.00	0.00
Standard Error[e]	0.04	0.04	0.01	0.00	0.00
1990 (lower 152 km) - 7/2-8/3					
Sample size[f]	2,239	1,389	255	0	0
RSD	0.58	0.36	0.06	0.00	0.00
Adjusted RSD[d]	0.75	0.21	0.04	0.00	0.00
Standard Error[e]	0.17	0.03	0.01	0.00	0.00
1991 (lower 152 km) - 7/8-8/1					
Sample size[f]	2,587	1,185	178	0	0
RSD	0.65	0.30	0.05	0.00	0.00
Adjusted RSD[d]	0.73	0.24	0.03	0.00	0.00
Standard Error[e]	0.01	0.01	<0.01	0.00	0.00
1992 (lower 152 km) - 7/6-7/30					
Sample size[f]	2,068	949	102	0	0
RSD	0.66	0.31	0.03	0.00	0.00
Adjusted RSD[d]	0.78	0.20	0.02	0.00	0.00
Standard Error[e]	0.04	0.02	<0.01	0.00	0.00

[a] Minimum lengths for RSD categories are (Gabelhouse 1984): Stock - 150 mm FL; Quality - 270 mm FL; Preferred - 340 mm FL; Memorable - 450 mm FL; and, Trophy - 560 mm FL.
[b] Year (sections sampled (taken from Hallberg 1980)) - sampling dates.
[c] Lengths were taken in 1985, but not reported in Holmes et al. (1986).
[d] RSD was adjusted to correct for bias due to the electrofishing boat (Clark and Ridder 1988).
[e] Standard error is for adjusted RSD only.
[f] Sample sizes do not correspond to RSD proportions because RSD proportions are weighted by abundance estimates in a stratified design (Clark 1989) and RSD is adjusted to correct for bias due to the electrofishing boat (Clark and Ridder 1988).

Appendix A8. Parameter estimates and standard errors of the von Bertalanffy growth model[a] for Arctic grayling from the Chena River, 1986-1988.

Parameter	Estimate	Standard Error
L_∞[b]	538	21
K[c]	0.10	0.01
t_0[d]	-1.72	0.11
$Corr(L_\infty, K)$[e]	-0.99	---
$Corr(L_\infty, t_0)$	-0.91	---
$Corr(K, t_0)$	0.95	---
Sample size	4,301	

[a] The form of the von Bertalanffy growth model (Ricker 1975) is as follows: $l_t = L_\infty (1 - exp(-K (t - t_0)))$. The parameters of this model were estimated with data collected during 1986 through 1988. This model was fitted to the data by nonlinear regression utilizing the Marquardt compromise (Marquardt 1963). The range of ages used to model growth was age 1 through age 11.

[b] L_∞ is the length a fish would achieve if it continued to live and grow indefinitely (Ricker 1975).

[c] K is a constant that determines the rate of increase of growth increments (Ricker 1975).

[d] t_0 represents the hypothetical age at which a fish would have zero length (Ricker 1975).

[e] $Corr(x,y)$ is the correlation of parameter estimates x and y.

APPENDIX B
Potential Bias in Abundance Estimation

Appendix B1. Estimates of potential bias in abundance estimates of Arctic grayling (≥ 150 mm FL) due to sampling selectivity in the Upper Chena section of the Chena River, 1987-1992.

Year	Without stratification[a]	With stratification[b]	Potential bias[c] (%)
1987	20,746	24,446	15.1
1988	14,444	NA[d]	0
1989	14,082	14,863	5.2
1990	16,643	19,061	12.7
1991	16,491	20,230	18.5
1992	16,168	18,033	11.5

[a] Without stratification is the estimated abundance of Arctic grayling (≥ 150 mm FL) if stratification by size had not been used to reduce bias due to size selectivity.

[b] With stratification is the estimated abundance of Arctic grayling (≥ 150 mm FL) if stratification by size had been used to reduce bias due to size selectivity.

[c] Potential bias is the difference between estimates without stratification and with stratification if stratification was needed, expressed as a percentage.

[d] NA means that a stratified estimate of abundance was not performed because changes in capture probability by size of fish were not detected.

APPENDIX C
Data File Listing

Appendix C1. Data files[a] used to estimate parameters of the Arctic grayling population in the Chena River in 1991 and 1992.

Data file	Description
U002ALA1.DTA	Population and marking data (first event) for Arctic grayling captured in the Lower Chena section of the Chena River (river km 0 to 72) 8 through 11 July 1991.
U002BLA1.DTA	Population and marking data (second event) for Arctic grayling captured in the Lower Chena section of the Chena River (river km 0 to 72) 15 through 18 July 1991.
U001ELA1.DTA	Population and marking data (first event) for Arctic grayling captured in the Upper Chena section of the Chena River (river km 72 to 152) 22 through 25 July 1991.
U001FLA1.DTA	Population and recapture data (second event) for Arctic grayling captured in the Upper Chena section of the Chena River (river km 72 to 152) 29 July through 1 August 1991.
U002ALA2.DTA	Population and marking data (first event) for Arctic grayling captured in the Lower Chena section of the Chena River (river km 0 to 72) 6 through 9 July 1992.
U002BLA2.DTA	Population and marking data (second event) for Arctic grayling captured in the Lower Chena section of the Chena River (river km 0 to 72) 13 through 16 July 1992.
U001ELA2.DTA	Population and marking data (first event) for Arctic grayling captured in the Upper Chena section of the Chena River (river km 72 to 152) 21 through 24 July 1992.
U001FLA2.DTA	Population and recapture data (second event) for Arctic grayling captured in the Upper Chena section of the Chena River (river km 72 to 152) 27 through 30 July 1992.

[a] Data files have been archived at, and are available from the Alaska Department of Fish and Game, Sport Fish Division, Research and Technical Services, 333 Raspberry Road, Anchorage, Alaska 99518-1599.

APPENDIX D
Pen Rearing Facility

Appendix D1. Memo concerning results of pen rearing of Arctic grayling in 1992.

MEMORANDUM

STATE OF ALASKA
Department of Fish and Game

TO: Distribution
Division of Sport Fish
Department of Fish and Game
Fairbanks

DATE: September 30, 1992

FILE:

TELEPHONE NO: 456-8819

SUBJECT: Chena River enhancemennt

FROM: Tim McKinley
Sport Fish Division
Department of Fish and Game
Fairbanks

As a first step towards rehabilitating the Chena River Arctic grayling stock, a total of 23,199 age-0 Arctic grayling were stocked into the Chena River at three locations on Sept. 11; 7,941 fish at 28 mile CHSR access, 7,941 at the Nordale Road bridge, and 7,317 just below the Chena River Dam. All fish were given an adipose clip one week prior to release; average length and weight was 65 mm and 2.70 g. Water temperature at the release sites was 4.4 C, while the pond temperature was 8.9 C. Based on the growth and survival of pond-reared fish stocked into the Chena River in the early eighties, we estimate approximately 6,000 of these fish will recruit to the fishery (f.l. ≥ 150 mm, age-1 and 2), at age two there will be 4,500 left in the fishery, and 1,000 will survive to spawn at age five. In a poor recruitment year (as this year is expected to be), only 2,000 wild fish may survive to age two, and only 575 to age five.

Prior to release, these grayling were reared in a floating net-pen for 42 days in a borrow pond at 33 mile CHSR. An estimated 33,868 grayling were stocked into the pen on July 30 when average length and weight was 38 mm and 0.51 g; surface water temperature was 20 C. The fish were fed approximately 114,550 g of commercial feed during the rearing period, and gained 45,364 g in total biomass, for a food conversion of 2.5. Water temperature during the rearing period averaged 16.1, 14.5, and 10.8 C, at depths of 0.1, 1.8, and 3.6 m below the surface. Arctic grayling of this size generally grow 0.05 mm per thermal unit (mm/TU); a thermal unit is one degree Celcius maintained over a 24 hour period. Based on this rate of growth, the growth of these fish was closely related to the average between water temperatures at 1.8 and 3.6 m, i.e. they probably spent most of their time between 1.8 and 3.6 m below the surface.

Only 4,717 mortalities were observed during the summer, which leaves 5,592 fish unaccounted for. Most mortalities sink to the bottom of the pen and some may pass through the mesh. Also, the initial number stocked into the pen was only an estimate, based on the estimated total weight of the stocking and the estimated average weight of the fish. If the initial average weight was actually 0.55 g instead of 0.51 g, this would account for 44% of the "missing" fish. We counted the fish as we fin-clipped them to get the actual number of fish released.

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Apart from staff time the cost of rearing the fish in the net pens was roughly $1550.00; $600.00 for feed, $600.00 for the feeder, and $350.00 for the boom holding the feeder. This equates to about $0.06 per fish released.

The Chena River Arctic grayling Conservation & Rehabilitation Plan calls for another stocking of pen-reared fingerlings into the Chena River next fall. My recommendation for next years pen-rearing is to start with 70,000 fish (0.50 g) early in July. This was the original plan for this year but due to the late occurrence of spawning we ended up with roughly half as many fish three weeks later than planned. The fish grow approximately 1 mm a day for every day spent in the warm water in July, but grow less than half that every day in September; its hard to make up for a late start by holding the fish longer into September. If necessary we should consider transporting the brood fish into warmer water (Clear Hatchery, a pond) to facilitate an earlier spawning.

Distribution: Andersen, Arvey, B. Clark, J. Clark, Doxey, Fleming, Hallberg, Merritt, Ridder, and Skaugstad